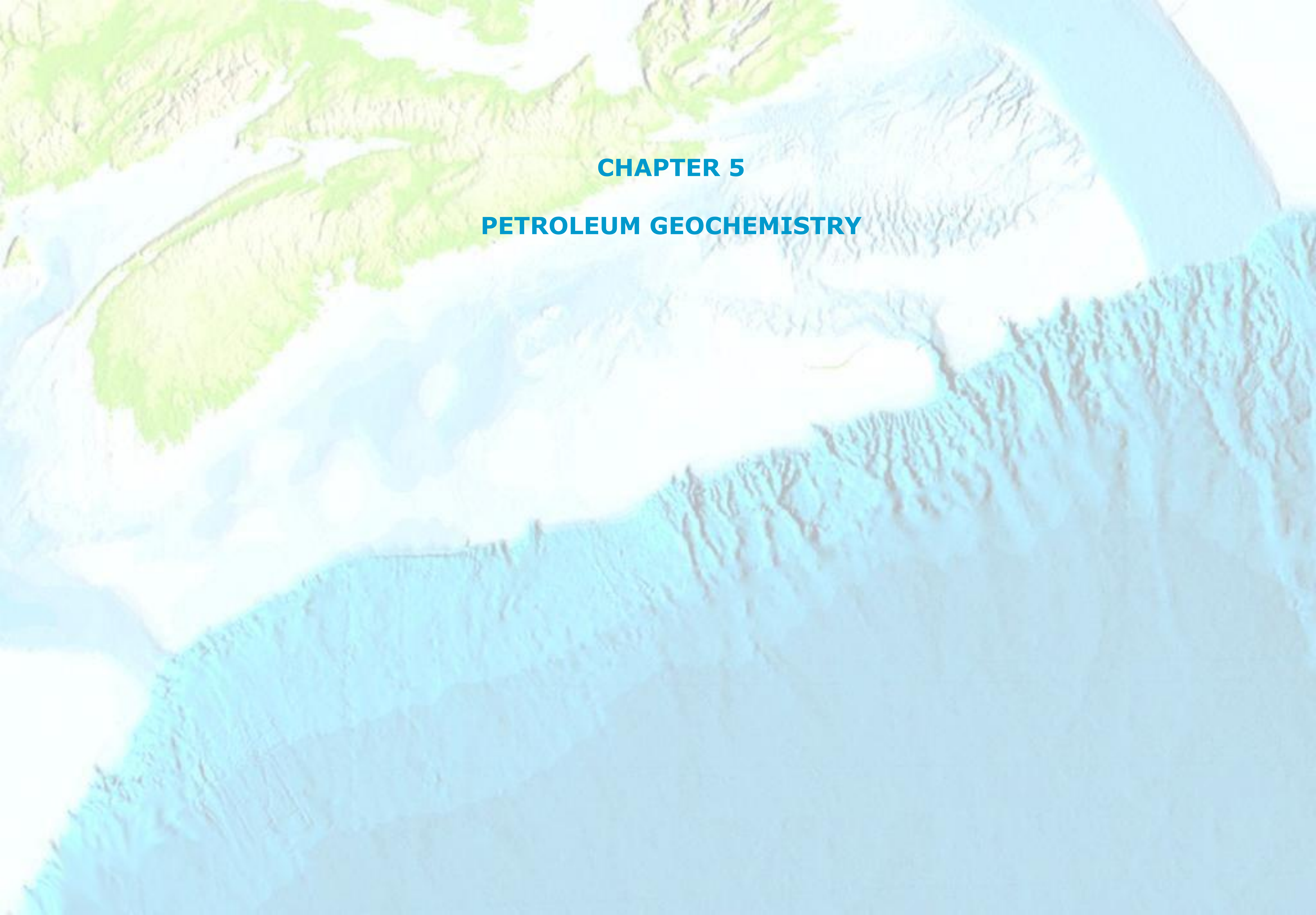
CHAPTER 5

PETROLEUM GEOCHEMISTRY



The Nova Scotia Margin

PFA 2011 Updated

&

Laurentian Sub-Basin

Petroleum Geochemistry

Introduction

Understanding the generative system is central to assess the petroleum system(s) of the Nova Scotia margin. The search for the source rocks generative of oil, gas & condensate discovered and yet to be discovered is therefore at the heart of the geochemistry project.
Maturity, of course, is the engine of hydrocarbon generation from these source rocks. Petroleum system modeling, which is a major part of the PLAY FAIRWAY ANALYSIS project, needs source rocks and maturity among many other elements and processes to play with.

Source rock search

•Review of existing TOC/Rock Eval data. Most of these data are stored in the GSC database (http://basin.gdr.nrcan.gc.ca/index_e.php). Some not entered in the GSC database were retrieved from the DMC database (http://ww1.cnsopbdmc.ca/dp/pages/apptab/ITabManager.html) requires an authorization).

•New TOC/Rock Eval data to complement these databases were needed to verify and confirm existing data, to extent data control toward the western margin and to check the pre-salt sedimentary series only penetrated by wells on the back shelf, where it is accessible at relatively shallow depths.

•Source rocks are not so evident to identify because drilling widely used oil-based mud. Other contaminants such as lignite, plastic, asphalt, rubber and paint have also been used. As a consequence, Oil Geochemistry was applied on oil and condensates of the Nova Scotia margin for attempting to identify oil families that would relate them to source rocks by their genetic signatures.

Oil and Condensates characterization

- Oil families identify the various types of source rocks they originate from (best case scenario). New GC and GCMS analyses of oil, condensates and hydrocarbon fluid inclusions were carried out focusing on their saturate fractions. A study of fluid inclusion in salt (Argo Salt) was carried out by Y. kettanah Professor Assistant at the Dalhousie University in Halifax as part of the Play Fairway Analysis project. Salt samples inclusions filled with hydrocarbon were selected by Y. Kettanah and submitted to biomarker analysis in order to complete the dataset of the geochemistry study.
  - Hydrocarbon inclusions essentially used for assessing possible source potential in the Triassic and Lower Jurassic. Source rocks in this interval are not documented because mostly not penetrated in the deep margin or not present (hiatus or unconformity) where penetrated. Triassic or Early Jurassic source rocks are expected to be oil-prone either lacustrine (Type 1;~West African offshore Bucomazi analog) in salt or post- salt situation and or marine (Type 2) in the Pliensbachian-Toarcian (Portugal, Morocco and French Schistes-Carton analogs).

•In the past, several attempts were made to characterize oil and condensates of the Nova Scotia margin. P. K. Mukhopadhyay (1990, 1991) conducted biomarker analysis on aromatic fractions. The Geological Survey of Canada presented a poster by Fowler and Obermajer (2000) on Nova Scotia oil families based on gasoline range compounds. These various approaches lacked references to genetic signatures capable of relating oil and condensates to source rock type and environment of deposition. The most significant data in a genetic sense remain the "standard" biomarkers of the saturate fraction and stable carbon isotope of oil and gas. Unfortunately there is no gas isotope data available in the various accessible databases and no gas samples are available for carrying out analysis.

- For oil, condensates and bitumen extracts, carbon isotope data were acquired and reported on by Mukhopadhyay (1991). These data are re-examined in this study.
- For "standard" biomarkers (saturates) of the Nova Scotia oil and condensates no database was ever constituted. There is only a few fingerprints, one of which is displayed in the Geological Survey of Canada poster by Fowler and Obermajer (2000). The reason evoked is that oils and condensates are light and therefore they do not contain significant amount of large molecules in the C_{27} to C_{30} range, where these biomarkers are. This gap in data control opened the opportunity to at least check what "standard" biomarkers may bring to improve understanding of the Petroleum Systems of the Nova Scotia margin.
- A regional geochemical survey, the confidentiality of which was lifted in April 2011, conducted by TDI-Brooks International, Inc. on the margin slope of Nova Scotia for a consortium (?) became accessible as a source of data for this study. The geochemical data of this survey consisting of carbon isotopes and molecular compositions (GC-GCMS) of piston-core seeps are also examined and discussed in this study.

Maturity

Maturity, of course, is the engine of hydrocarbon generation. Existing maturity data – Vitrinite Reflectance, SPI and TAI – are accessible from the on-line GSC database (http://basin.gdr.nrcan.gc.ca/index_e.php). New Vitrinite Reflectance data were acquired to complement the GSC database where needed , i.e. on the western margin of Nova Scotia.

Content of Petroleum Geochemistry Chapter 5 (Plates 5.X.X)

1. Source rock summary
2. Hydrocarbon occurrences
   - Significant discoveries and shows
   - Significant seeps on the Nova Scotia margin slope and Laurentian Sub-basin (TDI-Brooks regional geochemical survey)
3. PFA 2011 Data
   - Oil, condensates and rock extracts
   - Piston-core Seeps
4. PFA 2011 Source Rocks
5. Laurentian Sub-basin Data
6. Laurentian Sub-basin Sources Rocks
7. Conclusions

Source rock summary

Five (5) key source rocks:

1. **Lower Cretaceous – Aptian (deltaic)**
   - Intra-Aptian MFS (Naskapi)
2. **Lower Cretaceous – Berriasian (deltaic)**
   - Base age 137 Ma
3. **Upper Jurassic – Tithonian (transition from carbonate to deltaic environment)**
   - Tithonian MFS
   - The Tithonian source rock is of major importance as it is well defined, organic-rich and mature
4. **Middle Jurassic – Callovian**
   - Callovian MFS –Misaine
5. **Early Jurassic source complex– Liassic (Sinemurian/Pliensbachian/Toarcian)**
   - Deposited immediately post-rift, hypersaline (gammacerane) to carbonate marine environment
   - Not penetrated. Inferred from the Moroccan and Portuguese conjugate margins
   - Because not penetrated, these Early Jurassic source rocks are taken as one source complex

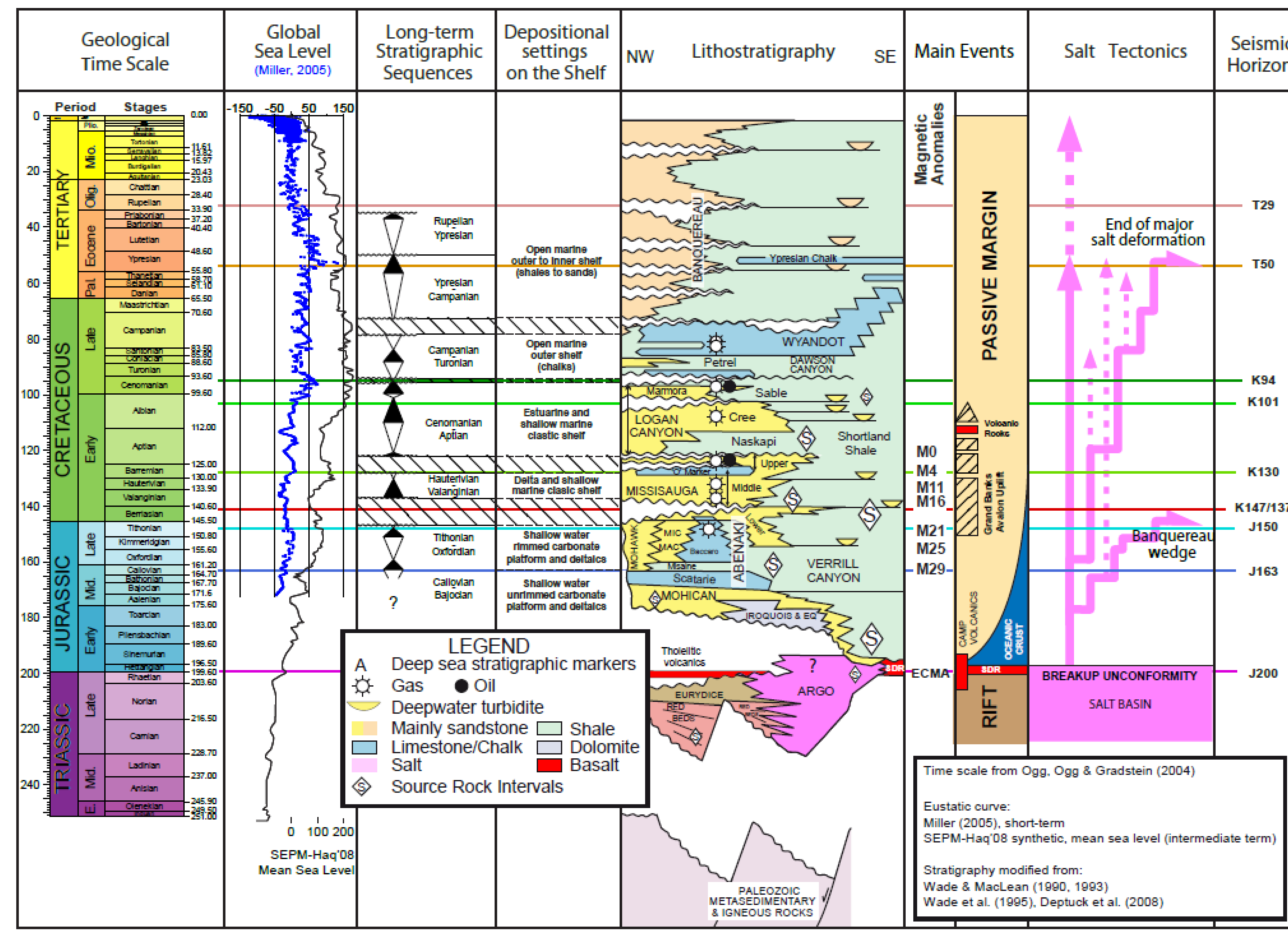


Figure 1: Chronostratigraphic chart developed for the Play Fairway Analysis project. Source rocks are outlined by diamond-shaped boxes including a S for source rock. Large and small diamond boxes indicate major and minor source rocks, respectively. The Aptian (Naskapi) source rock is minor as it is mature only over a limited area of the margin. The Valanginian source rock is considered minor as it is relatively limited in organic matter. However, it reflects and accounts for organic matter present in the Lower Cretaceous (Missisauga). The Tithonian source rock is of major importance as it is well defined, organic-rich and mature. The Misaine source rock is considered because it is a maximum flooding surface well identified where penetrated. It was encountered and documented in two wells only located on the Jurassic carbonate shelf. Spatially limited and poor data support makes it a source rock of minor importance. Yet not penetrated, the Early Jurassic source complex is considered major. Its existence is strongly supported by analogs on the conjugate margins of Portugal and Morocco (see Plate X-X-X).

Oil and Gas Occurrences

PFA 2011 and Laurentian Sub-basin

and

Regional Comparison of Hydrocarbon Fluid Bulk Composition, Nova Scotia Margin

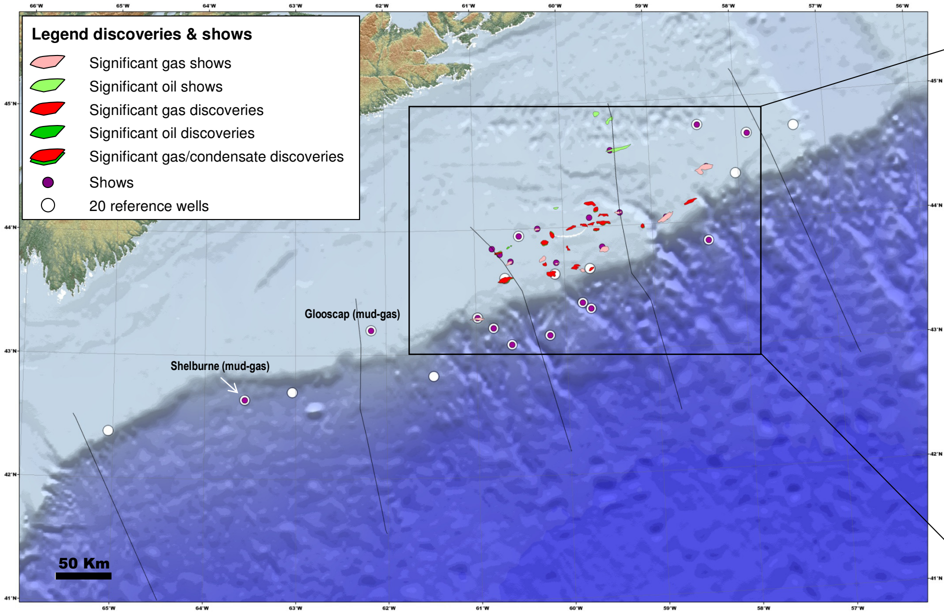


Figure 1: Distribution of significant discoveries, shows and minor mud-gas shows

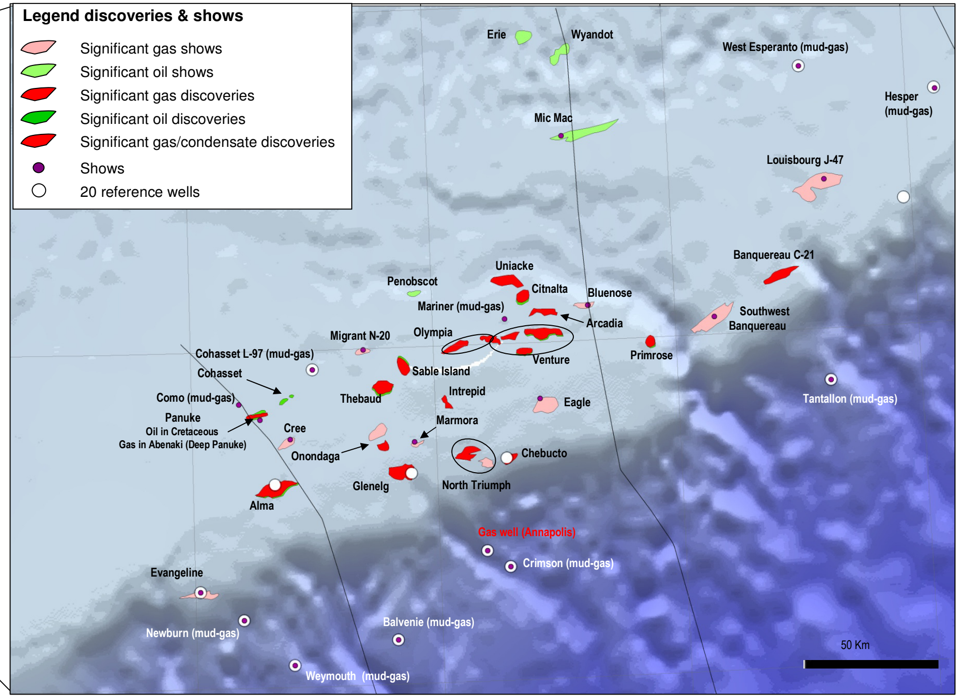


Figure 2: Zoom on the distribution of significant discoveries and shows.

Figures 1 & 2 display the distribution of significant oil, condensates and gas discoveries as well as of mud-gas shows. Significant oil, condensates and gas discoveries are located in the Sable and the Abenaki sub-basins. Significant gas shows are located in the Sable sub-basin (Cree, Onondaga and Eagle). East of the Sable sub-basin (Southwest Banquereau, Louisbourg) and West of the Sable sub-basin (Evangeline). Significant oil shows are located in the Northeastern part of the Abenaki sub-basin (Penobscot, Erie, Wyandot and Mic Mac)

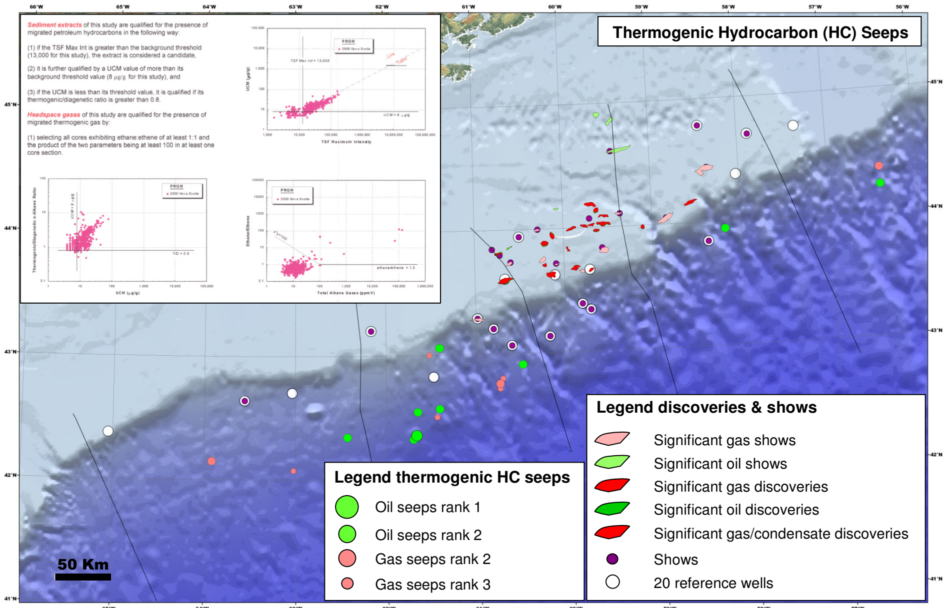


Figure 3: Distribution of significant discoveries, shows, minor mud-gas shows and thermogenic hydrocarbon seeps by *Bernard et al. 2000)*

A regional geochemical survey, the confidentiality of which was lifted in April 2011, conducted by TDI-Brooks International, Inc. on the shelf slope of Nova Scotia for a consortium (?) became accessible as a source of data for this study. The distribution of thermogenic hydrocarbon seeps is shown in Figure 3. The geochemical data of this survey consisting of carbon isotopes and molecular compositions (GC-GCMS) of piston-core seeps are also examined and discussed in this study.

Reference:
Bernard B. B., Allan K. A. and McDonald T; J. (2000) Regional geochemical survey for 2000 Nova Scotia Consortium. SGE Program. TDI-Brooks International, Inc. report, December 2000.

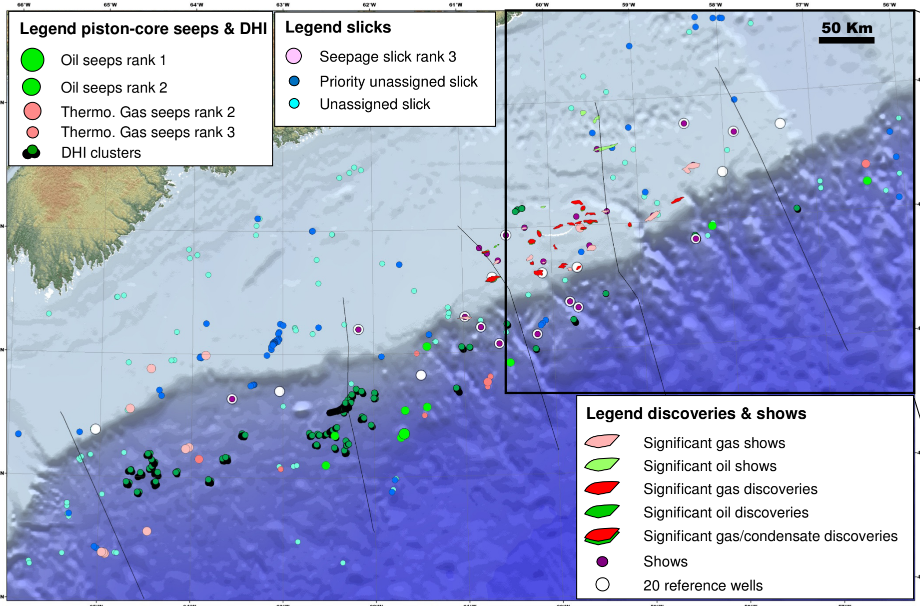


Figure 1: Distribution of significant discoveries, shows, minor mud-gas shows, thermogenic hydrocarbon seeps by Bernard et al. 2000), DHI and satellite oil slicks by (NPA-Fugro).

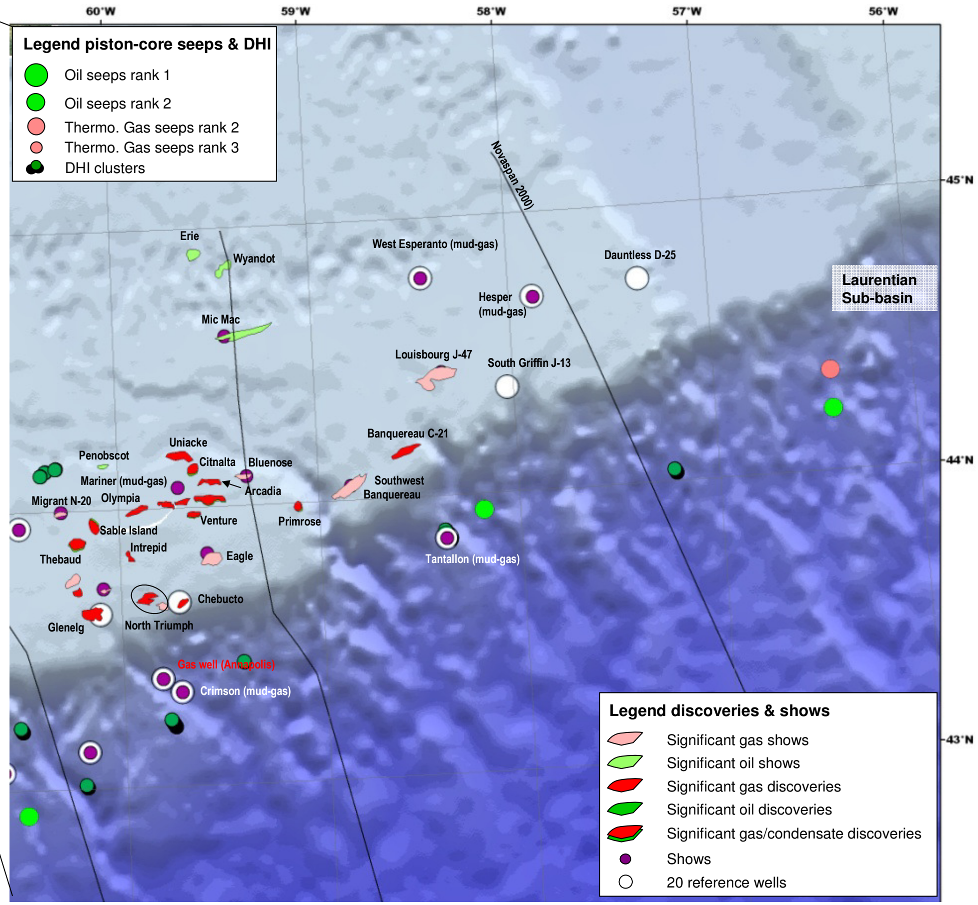


Figure 2: Zoom on the distribution of significant discoveries, shows and seeps from the piston-core by TDI-Brooks International, Inc.

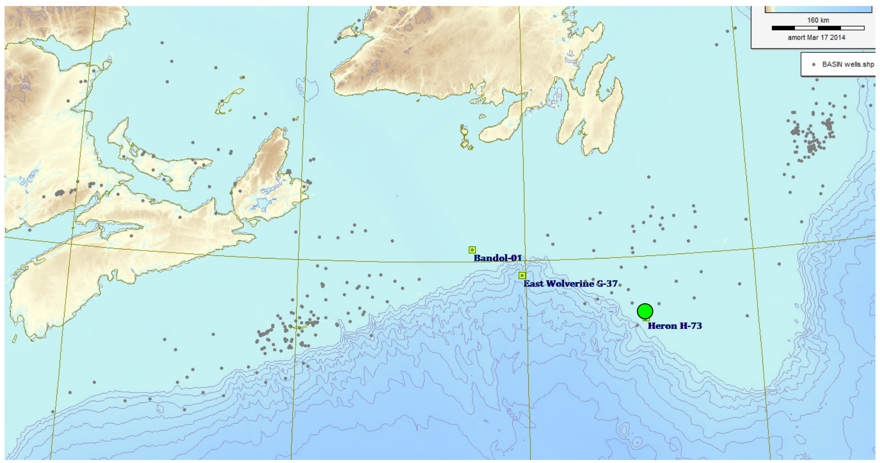
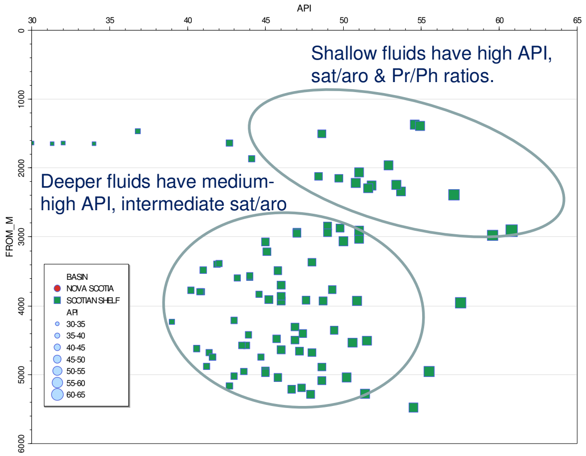
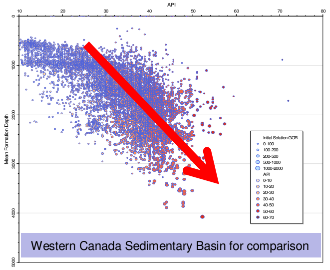


Figure 3: Location of three Laurentian – South Whale wells. Bandol-01 and East Wolverine G-37 are D&A. Heron tested oil in the Petrel Member (DST#6 at 2300m MD)

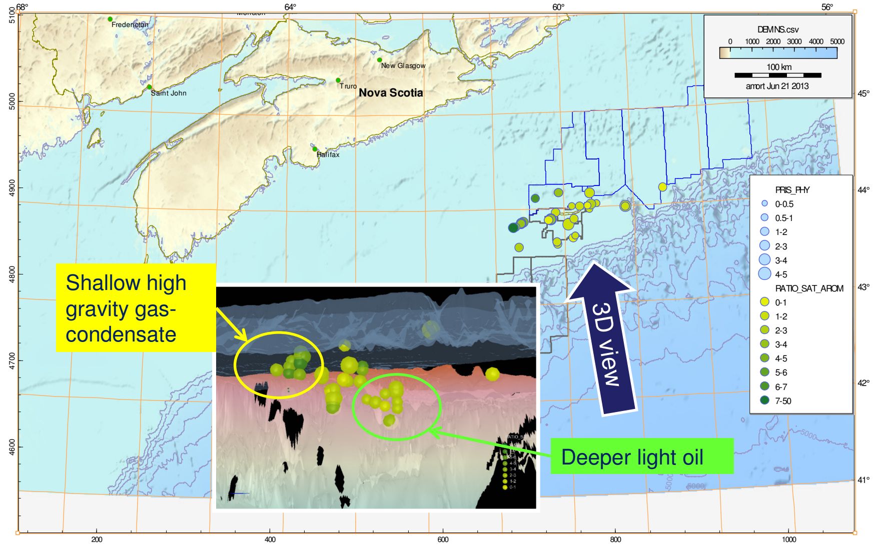
Figures 1 & 2 display the distribution of significant oil, condensates and gas discoveries as well as of mud-gas shows. Significant oil, condensates and gas discoveries are located in the Sable and the Abenaki sub-basins. Significant gas shows are located in the Sable sub-basin (Cree, Onondaga and Eagle). East of the Sable sub-basin (Southwest Banquereau, Louisbourg). Significant oil shows are located in the Northeastern part of the Abenaki sub-basin (Penobscot, Erie, Wyandot and Mic Mac). Also, significant seeps (rank 2) from TDI-Brooks piston-core survey are located on the shelf slope and toward the Laurentian Sub-basin.

Regional comparison of bulk fluid composition





Plot of API gravity versus depth for fluids occurring on the Scotian Shelf (left) reported in the BASIN database, indicating an inversion in the more typical trend of increasing API with depth as shown in the example from the Western Canada Sedimentary Basin (above). The map (right) shows a 3D view of selected samples in the subsurface.

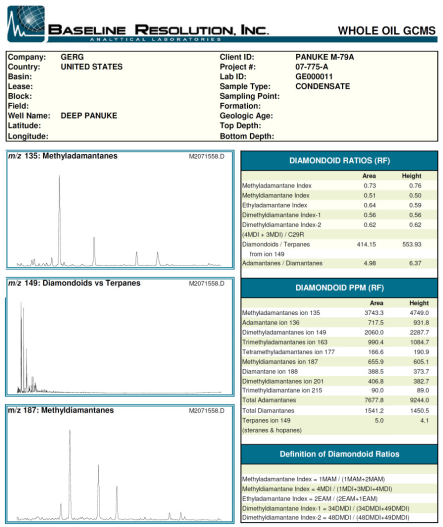


A cursory investigation of some of the basic properties of fluids occurring in the Scotian Basin revealed an interesting trend where by fluids at greater depths are of lower gravity than very high GOR shallow fluids. There are at least two possible explanations for this observed trend:

1. Shallower fluids are light fractionates of deeper oil pools

2. Deeper fluids are generated from a more oil-prone source rock

An example of the deeper fluid is the Deep Panuke gas condensate accumulation. Geochemical analysis of Deep Panuke fluids by Sassen & Post (2007) suggest that the source for these fluids is not the same as the source rock which is thought to have generated other fluids in the Sable sub-basin. One of the interesting results of the geochemical analysis is shown in the image of GCMS traces taken from the Baseline Resolution laboratory report (right). These ion chromatograms show very high concentrations of diamondoid compounds in the oils, indicating that the fluids have undergone extensive thermal cracking, and must therefore have originated from a deep source, postulated to be a Type II Marine shale.


BASELINE RESOLUTION, INC.
ANALYTICAL LABORATORIES
WHOLE OIL GCMS

Company: GERG
Country: UNITED STATES
Basin:
Lease:
Block:
Field:
Well Name: DEEP PANUKE
Latitude:
Longitude:
Client ID: PANUKE M-79A
Project #: 07-775-A
Lab ID: GE000011
Sample Type: CONDENSATE
Sampling Point:
Formation:
Geologic Age:
Top Depth:
Bottom Depth:

m/z 135: Methyladamantanes M2071558.D

m/z 149: Diamondoids vs Terpanes M2071558.D

m/z 187: Methyldiamantanes M2071558.D

DIAMONDOID RATIOS (RF)

	Area	Height
Methyladamantane Index	0.73	0.76
Methyldiamantane Index	0.51	0.50
Ethyladamantane Index	0.64	0.59
Dimethyldiamantane Index-1	0.56	0.56
Dimethyldiamantane Index-2	0.62	0.62
(4MDI + 3MDI) / C29R		
Diamondoids / Terpanes from ion 149	414.15	553.93
Adamantanes / Diamantanes	4.98	6.37

DIAMONDOID PPM (RF)

	Area	Height
Methyladamantanes ion 135	3743.3	4749.0
Adamantane ion 136	717.5	931.8
Dimethyladamantanes ion 149	2060.0	2287.7
Trimethyladamantanes ion 163	990.4	1084.7
Tetramethyladamantanes ion 177	166.6	190.9
Methyldiamantanes ion 187	655.9	605.1
Diamantane ion 188	388.5	373.7
Dimethyldiamantanes ion 201	406.8	382.7
Trimethyldiamantane ion 215	90.0	89.0
Total Adamantanes	7677.8	9244.0
Total Diamantanes	1541.2	1450.5
Terpanes ion 149 (steranes & hopanes)	5.0	4.1

Definition of Diamondoid Ratios

Methyladamantane Index = 1MAM / (1MAM+2MAM)
Methyldiamantane Index = 4MDI / (1MDI+3MDI+4MDI)
Ethyladamantane Index = 2EAM / (2EAM+1EAM)
Dimethyldiamantane Index-1 = 34DMDI / (34DMDI+49DMDI)
Dimethyldiamantane Index-2 = 48DMDI / (48DMDI+49DMDI)

"The preliminary conclusion is that the Deep Panuke condensate is derived from a marine Type II source rock, whereas the condensate found in the siliciclastic reservoirs of the Sable sub-basin is largely derived from a source rock with dominance of Type III kerogen derived from higher plants. In other words, there appear to be different source rocks in different geologic settings in the Sable sub-basin."

Sassen, R. and Post, P.J., 2007
Geochemical Evaluation of Condensate from Deep Panuke, Offshore Nova Scotia.
Canada-Nova Scotia Offshore Petroleum Board Sample Report SR(E)2007-5, 7 pages (plus appendices & tables).

Data from

PFA 2011

ROCK DATA

The basic geochemical data available on line consist of source rock and maturity data for the Scotian Shelf and the Scotian Slope as well as the South Grand Banks, would the latter be necessary. There are TOC and Rock Eval data for 59 wells (Figure ***) and maturity data for 79 wells (Figure ***).

Rock Eval and TOC

The source rock data consist of TOC and Rock Eval analyses characterizing the source rock potential of well cuttings and cores. The TOC is a measure of organic carbon content expressed in weight % of the rock. The TOC analysis may be obtained by different procedures, but also directly from the Rock Eval analysis, depending on the type of analyzer. The analytical results produced by TOC and Rock Eval analyses are as follows:

- TOC: Organic Carbon content
- Free hydrocarbons content in the rock sample: S1 value
- Remaining hydrocarbon potential (HC not realized): S2 value
- Oxidation "potential" contained in the organic matter of the kerogen: S3 value
- Tmax: Maximum pyrolysis temperature, at which the remaining hydrocarbon potential (S2) is generated. Due to its specificity, Tmax is a maturity measurement, which can be correlated to other maturity parameters such as Vitrinite Reflectance, Thermal Alteration Index (TAI), Spore Color Index (SPI) and others.

The Rock Eval data populating the GSC on-line database were generated by various laboratories including the geochemistry laboratory of the GSC-Calgary.

Maceral

Maceral data derived from microscopic analysis of kerogen are available from Mukhopadhyay's reports (1989, 1990a, 1990b and1991) and Mukhopadhyay et al. publications (1990 and 1995). All unpublished reports are available from CNSOPB DMC database. Over the years, P. K. Mukhopadhyay has defined a maceral description chart specially adapted to the Nova Scotia margin. That chart is displayed in Table 1 (right) to provide the reader with the descriptive code used in the following plates.

Maturity

Maturity data used in this study consist essentially of Vitrinite Reflectance. The GSC online database is populated mainly by data from various laboratories but mainly from Avery and Mukhopadhyay. New Vitrinite Reflectance data were acquired for only two wells, so adding two maturity profiles to the 79 existing ones. For wells with multiple maturity datasets from different sources, there are conflicting maturity profiles.

OIL & CONDENSATE DATA

Existing accessible oil and condensate data, such as GC traces, aromatic biomarkers, gasoline range GC traces are neither numerous nor that meaningful. Interpretation of these data was tentative not contributing clear cut solutions to understanding the petroleum systems of the Nova Scotia margin. These data yet carried out on samples from DST, PT (Production test) and other tests are usually not tainted by mud additive. In case of doubt, checks are performed and discussed. New biomarker data were acquired on 15 oils and condensates samples for this study with a particular focus on the saturate fractions of these samples. Saturate biomarkers of the steranes and hopanes/triterpanes size were often discarded as their concentration are low in condensates.

PISTON-CORE SEEPS DATA

Seeps data from the regional geochemical survey on the slope of the Nova Scotia margin by TDI-Brooks International, Inc. were made available to this study end of March (2011) when confidentiality on the report was released.

Table *: Amorphous Organic Matter Related to Kerogen and Hydrocarbon Potential**

Kerogen Type	Organic facies: Amorphous Maceral Type (Fluorescence)	Organic facies: Associated Major Macerals	Organic facies: Environment of Deposition	Range of Hydrogen Index (mg HC/g TOC)	Pyrolisis-GC Pattern	Oil/Gas Potential[+]
I	Sapro I* (golden yellow)	Alginite	Lakes or algal mat (shallow marine or freshwater)	Greater than 800	Mainly n-alkanes between C_{10} - C_{30}	Oil + Condensate + Gas[#] (80%)
IIA	Sapro IIA* (yellow brown)	Alginite, Sapro I, Part. Liptinite A & B, Liptodetrinite	Lagoon or lakes (marine or fresh). Upwelling area (shallow or deep marine)	550 - 800	Dominant cyclo- and normal alkanes between C_8 - C_{27}	Oil + Condensate + Gas[#] (60 - 90%)
IIA-IIB	Sapro IIA* + Sapro IIB* (brown or orange)	Part. Liptinite A & B, Liptodetrinite, Sapro-Vitrinite	Upwelling region, prodelta, Lacustrine delta, deep marine anoxia	300 - 600	Mixed cyclo- and normal alkanes and aromatics between C_6 - C_{20}	Oil + Condensate + Gas[#] (50%) (50%)
IIB	Sapro IIB* (brown)	Part. Liptinite A & B, Sapro IIA, Desmocollinite	Deltaic marsh, lagoon, back-barrier, deep marine anoxia	225 - 400	Mixed aromatics and cycloalkanes	Condensate + Gas + Oil (50%) (40%) (10%)
IIB-III	Sapro IIB + Humosapro	Telocollinite, Part. Liptinite B	Partially oxic prodelta or shallow marine, and lagoon	100 - 250	N-alkanes up to C_{12} and Low molecular wt. aromatics, and phenol	Gas + Condensate (70%) (30%)
III	Humosapro* (nonfluorescent to dark brown)	Part. Liptinite B, Telocollinite	Delta swamp, partially oxic. Shallow or deep marine basins	50 - 125	Mainly aromatics and n-alkanes up to C_{14} and phenol	Gas (>80%)
IV	Macrinite (nonfluorescent)	Fusinite, Macrinite, Recycled vitrinite	Oxic swamp, tidal flats or deep marine basins	Less than 50	Minor hydrocarbons	Non source

Sapro I*, Sapro IIA*, Sapro IIB*, Humosapro* = Sapropelinite I, IIA, IIB and Humosapropelinite; Part: Liptinite = Particulate Liptinite A & B

Sapropelinite = Bituminite = Amorphinite. Particulate liptinite A = Lamalginite. Particulate liptinite B = Exinite & Resinite

+ Under normal Eh/Ph condition without diagenetic oxidation; # Generation starts beyond 1.0% Ro

Table 1: P. K; Mukhopadhyay's maceral description chart

Reference:
P. K. Mukhopadhyay and Wade J. A. 1990. Organic facies and maturation of sediments from three Scotian Shelf wells. Bulletin of Canadian Petroleum Geology, Vol. 38, No. 4, pp. 407-425 (DEC 1990).

DATA QUALITY

Top	Bottom	Units	Mud	Mud Additives	Event	Comments
3513		M			FISH	SURVEY TOOL LEFT IN THE HOLE - RECOVERED WITH AN OVERSHOT
4119		M			FISH	DRILL STRING STUCK IN THE HOLE AS A RESULT OF A WELL KICK - ADDED DIESEL AND WORKED PIPE FREE
5241		M			FISH	PIPE STUCK IN THE HOLE - PIPE WAS BACKED-OFF AND CEMENTED IN THE HOLE - WELL WAS SIDETRACKED
4119		M			KICK	POSITIVE FLOW CHECK - MUD WEIGHT RAISED BY 510 KG/M3 (FROM 1140 TO 1650 KG/M3) TO KILL THE WELL
4134		M			LOST CIRC	NO FURTHUR LOST CIRCULATION DATA FOUND IN WELL HISTORY REPORT
5157		M			LOST CIRC	
5193		M			LOST CIRC	
108	368	M	SEAWATER - VISCOUS SLUGS		MUD	
368	3261	M	SEAWATER - KCL		MUD	
3261	4141	M	FRESHWATER - GEL - LIGNOSULPHONATE	DIESEL (4119 & 4141 M), PIPELAX (4119 M), CHROME LIGNITE (4119 M)	MUD	
4141	5253	M	FRESHWATER - GEL - CHROME LIGNITE	CHROME LIGNITE (4141-5253 M), KWIKSEAL & WALNUT (5205 & 5253 M), X-PEL-G (4553, 4735, 4753 & 5081 M)	MUD	
4785	5083	M			MUD MOTOR	DYNA-DRILLED INTERVAL
5083	5157	M			MUD MOTOR	TURBO DRILLED INTERVAL
5205	5227	M			MUD MOTOR	
4913	5085	M			MUD MOTOR*	DYNA-DRILLED INTERVAL (DIRECTIONAL DRILLING INTERVAL IN SIDETRACKED HOLE)
5095	5148	M			MUD MOTOR*	TURBO DRILLED INTERVAL IN SIDETRACKED HOLE

Figure 1: Glenelg J-48 - Example of a mud scheme used in many drilling operations

Rock Eval and TOC data

Oil-based mud and various additives were used in an estimated 80% of the wells analyzed constitutes a serious problem for interpreting geochemical data , in particular , identifying source rocks on the Nova Scotia margin.

Maceral data

Maceral data obtained by microscopic observation offers the advantage that part of the contaminants from the mud can be identified and discarded from the kerogen composition. However, mud additives such as lignite and gilsonite may not always be easily separated from the in-situ sedimentary kerogen. However, TOC/Rock Eval data associated to the maceral analyses are contaminated by the mud additives , which make them unreliable.

Oil and Condensate data

Oil and condensate are not subject to too much distortion by mud additives as they are collected from tests. However, in case of doubt, possible contamination must be cautiously be examined.

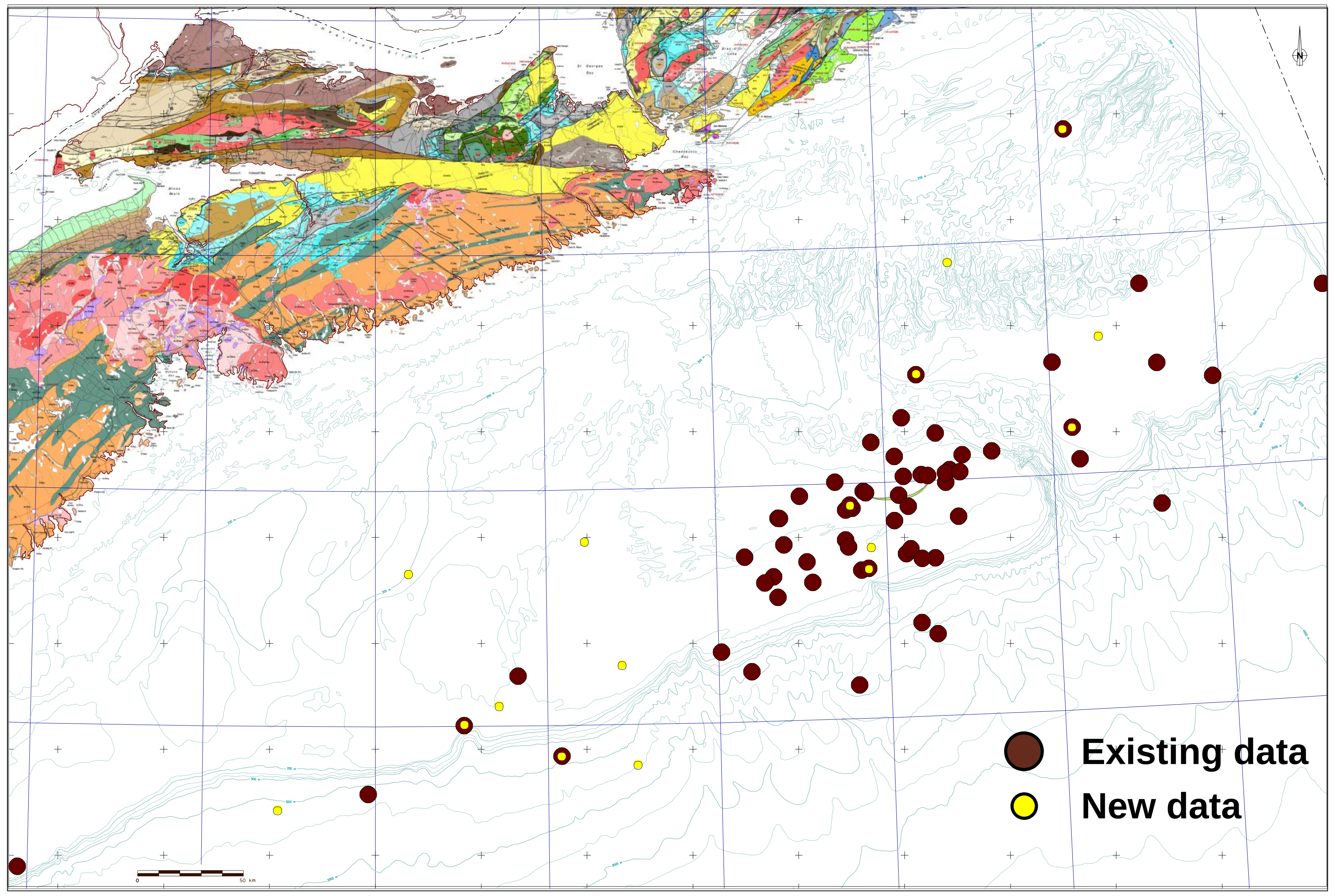
Rock extract data

Rock extract data are highly susceptible to oil-based mud contamination.

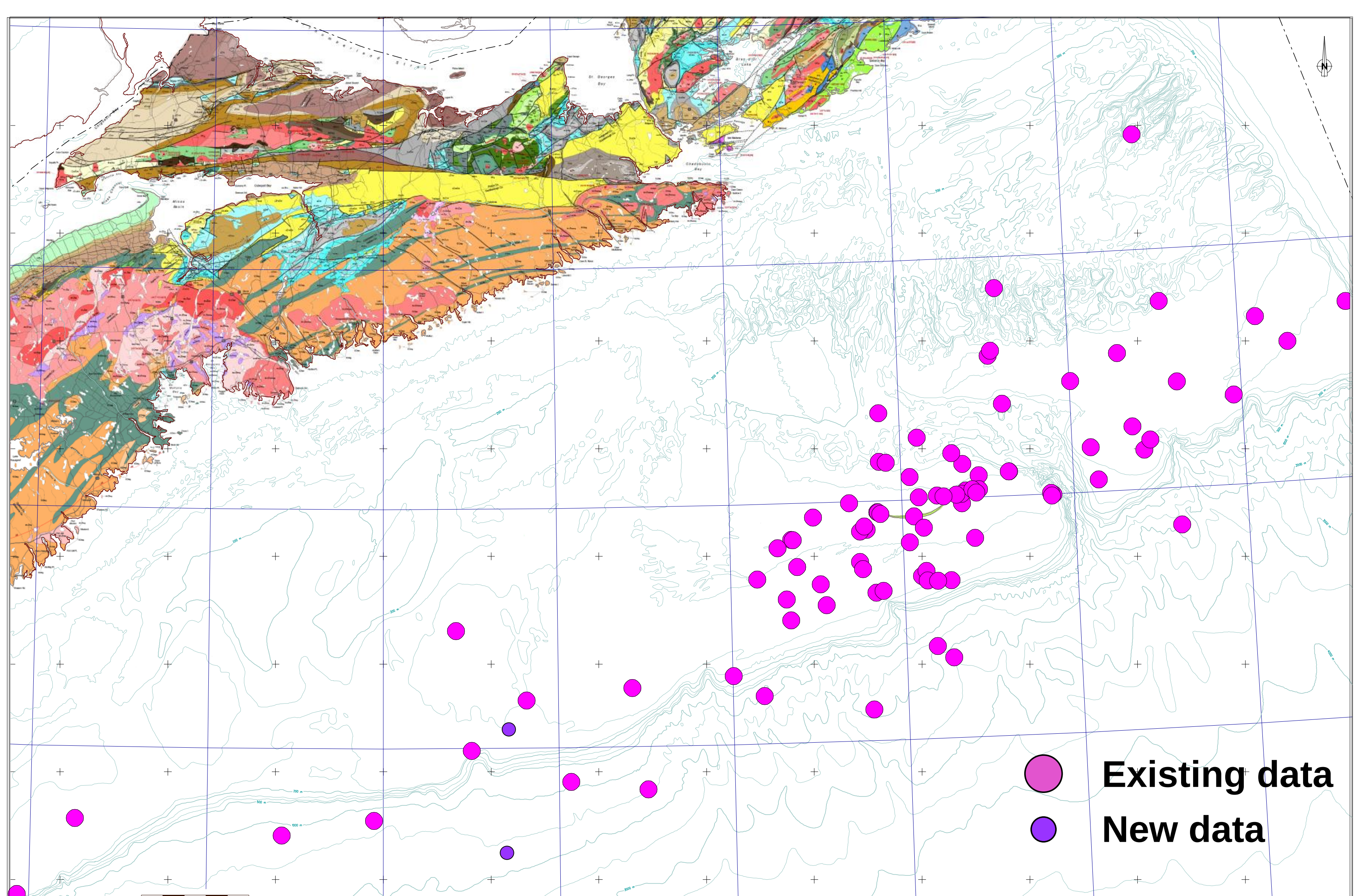
Piston-core seeps data

Seeps data from the regional geochemical survey on the slope of the Nova Scotia margin by TDI-Brooks International, Inc., deserve some careful examination of possible contamination by natural organic material present in the sediments near sea floor collected by piston-coring. This contamination cannot be eliminated, but avoided as much as possible using geochemical methods such as chromatography to discard samples containing large amount of recent natural organic matter.

TOC/ROCK EVAL DATA



MATURITY DATA



TOC/ROCK EVAL DATA

Online GSC Basin Database

54 shelf wells

Abenaki J-56
Alma F-67
Alma K-85
Arcadia J-16
Argo F-38
Bluenose 2G-47
Chebucto K-90
Citadel H-52
Citnalta I-59
Cohasset A-52
Cohasset D-42
Cohasset L-97
Cree E-35
Dauntless D-35
Demascota G-32
Eagle D-21
Evangeline H-98
Glenelg E-58
Glenelg J-48
Glooscap C-63
Intrepid L-80
Iroquois J-17
Louisbourg J-47
Merigomish C-52
Migrant N-20
Mohican I-100
North Triumph B-52
North Triumph G-43
Olympia A-12
Onondaga B-96
Onondaga E-84
Onondaga B-84
Penobscot L-30
Peskowesk A-99
Sable Island C-67
Sable Island E-48
Sable Island O-47
Saint Paul P-91
South Desbarres O-76
South Griffin J-13
South Sable B-44
South Venture O-59
S.W. Banquereau F-34
Thebaud C-74
Thebaud I-93
Thebaud P-84
Uniacke G-72
Venture B-43
Venture B-52
Wenonah J-75
W. Chebucto K-20
West Olympia O-51
West Venture N-91
Whycocomagh N-90

7 slope wells

Acadia K-62
Albatross B-13
Annapolis G-24
Balvenie B-79
Crimson F-81
Newburn H-23
Tantallon M-41

Wells from the DMC database

2 shelf wells

West Esperanto B-78 (no Excel datasheet)
Bonnet P-23

TOC/Rock Eval & Maturity data newly acquired

TOC/Rock Eval		Nb. of Samples
• Acadia K-62	4000m to TD (~5300m) +(FI basal carbonates)	69
• Shelburne G-29	3000m to TD	70
• Torbrook C-15	2600m to TD (~3600m	54
• Shubenacadie H-100	3200m to TD (~4200m)	41
• Oneida O-25	3100m to TD (~4100m)	102
• Sambro I-29	1000m to 1600m	21
• Ojibwa E-07	1400m to TD (~2300m	69
• Glenelg J-48	4500m to TD (~5100m)	39
• Marmora C-34	3800m-3900m	22
• Chippewa L-75	5900'-6972'	23
• Citadel H-52	5500'-5666'	12
• Emerillon C-56	9250'-10750'	48
• Erie D-26	5500'-7995'	57
• Moheida P-15	3300m-3900m	53
• Mohican I-100	4200m-4300m	13
• Argo F-38	10000'-11110' (TD) OK	7
• Iroquois J-17	4485'-5890' (17) and 6650'-6845' (9) oil stains anhydrite	80
Vitrinite Reflectance		
• Torbrook C-15	2835m-3600m	23
• Moheida P-15	10810'-12860'	27

MATURITY DATA

Online GSC Basin Database

79 shelf wells

Abenaki J-56
Alma F-67
Arcadia J-16
Banquereau C-21
Bluenose 2G-47
Bluenose G-47
Bonnet P-23
Chebucto K-90
Chippewa L-75
Citadel H-52
Citnalta I-59
Cohasset A-52
Cohasset D-42
Cohasset L-97
Cree E-35
Dauntless D-35
Demascota G-32
Dover A-13
Eagle D-21
Evangeline H-98
Glenelg J-48
Glooscap C-63
Hesper I-52
Intrepid L-80
Merigomish C-52
Jason C-20
Louisbourg J-47
Mic Mac H-86
Mic Mac J-77
Migrant N-20
Missisauga H-54
Mohawk B-93
Mohican I-100
Naskapi N-30
North Banquereau I-13
North Triumph B-52
North Triumph G-43
Olympia A-12
Oneida A-12
Onondaga B-96
Onondaga E-84
Panucke B-90
Penobscot B-41
Penobscot L-30
Primrose 1A A-41
Primrose A-41
Primrose F-41
Primrose N-50
Sable Island 3H-58
Sable Island 4H-58
Sable Island C-67
Sachem D-76
Sable Island E-48
Sable Island O-47
Saint Paul P-91
Sauk A-57
South Desbarres O-76
South Griffin J-13
South Sable B-44
South Venture O-59
S.W. Banquereau F-34
Thebaud C-74
Thebaud I-93
Thebaud P-84
Triumph P-50
Uniacke G-72
Venture B-13
Venture B-43
Venture B-52
Venture D-23
Venture H-22
Wenonah J-75
West Chebucto K-20
West Esperanto B-78
West Olympia O-51
West Venture C-62
West Venture N-91
Whycocomagh N-90
Wyandot E-53

9 slope wells

Acadia K-62
Albatross B-13
Annapolis G-24
Balvenie B-79
Crimson F-81
Newburn H-23
Shelburne G-29
Shubenacadie H-100
Tantallon M-41

MATURITY DATA (continued)

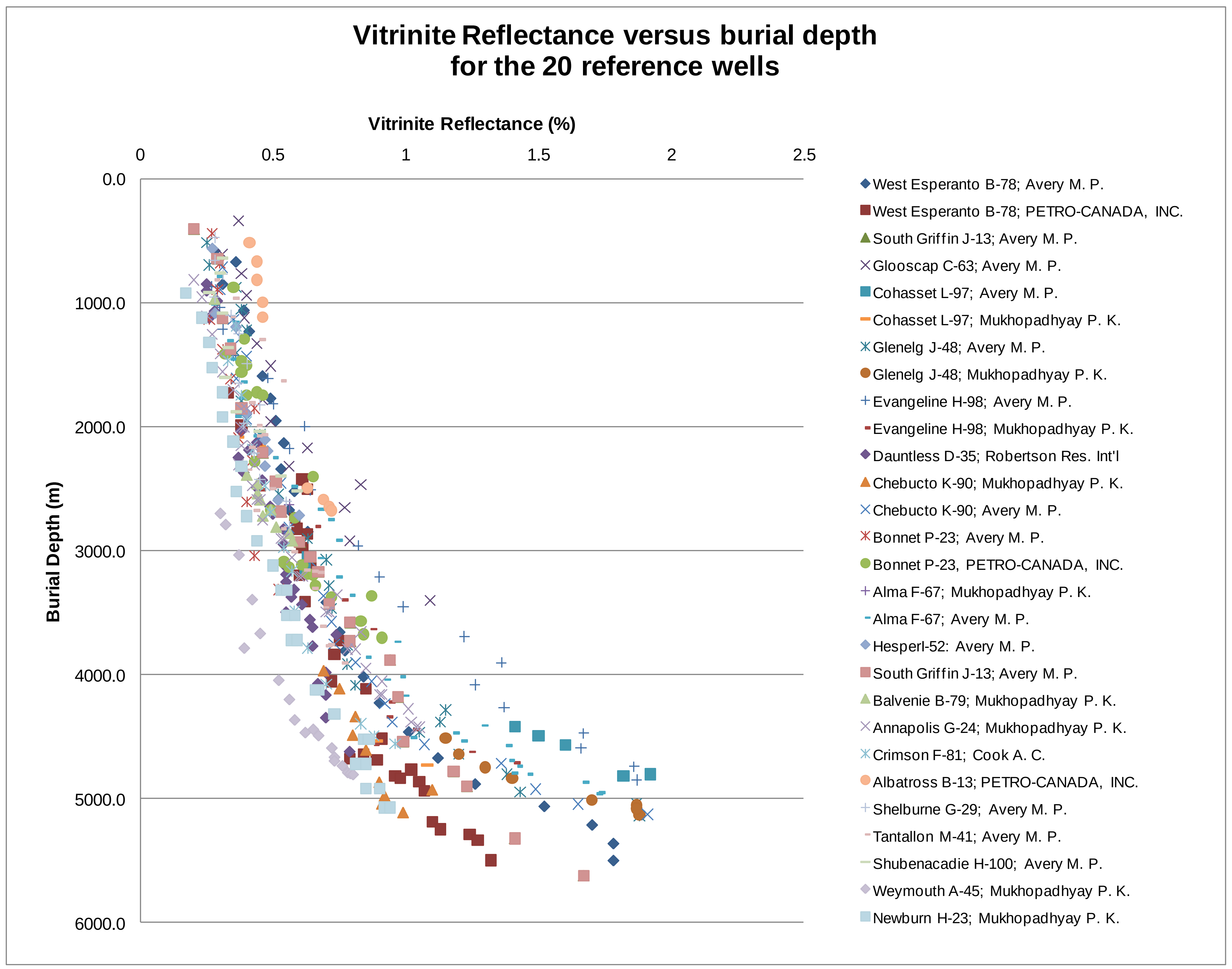
Distribution of Vitrinite Reflectance data versus burial depth for the 20 reference wells

The diagram of Figure 1 displays Vitrinite Reflectance data per well for the 20 wells of reference. The analyst name is provided In the inset list. In cases, wells were analyzed by several laboratories that are identified by more than one analysts names. Sometimes, only the laboratory is known and therefore listed.

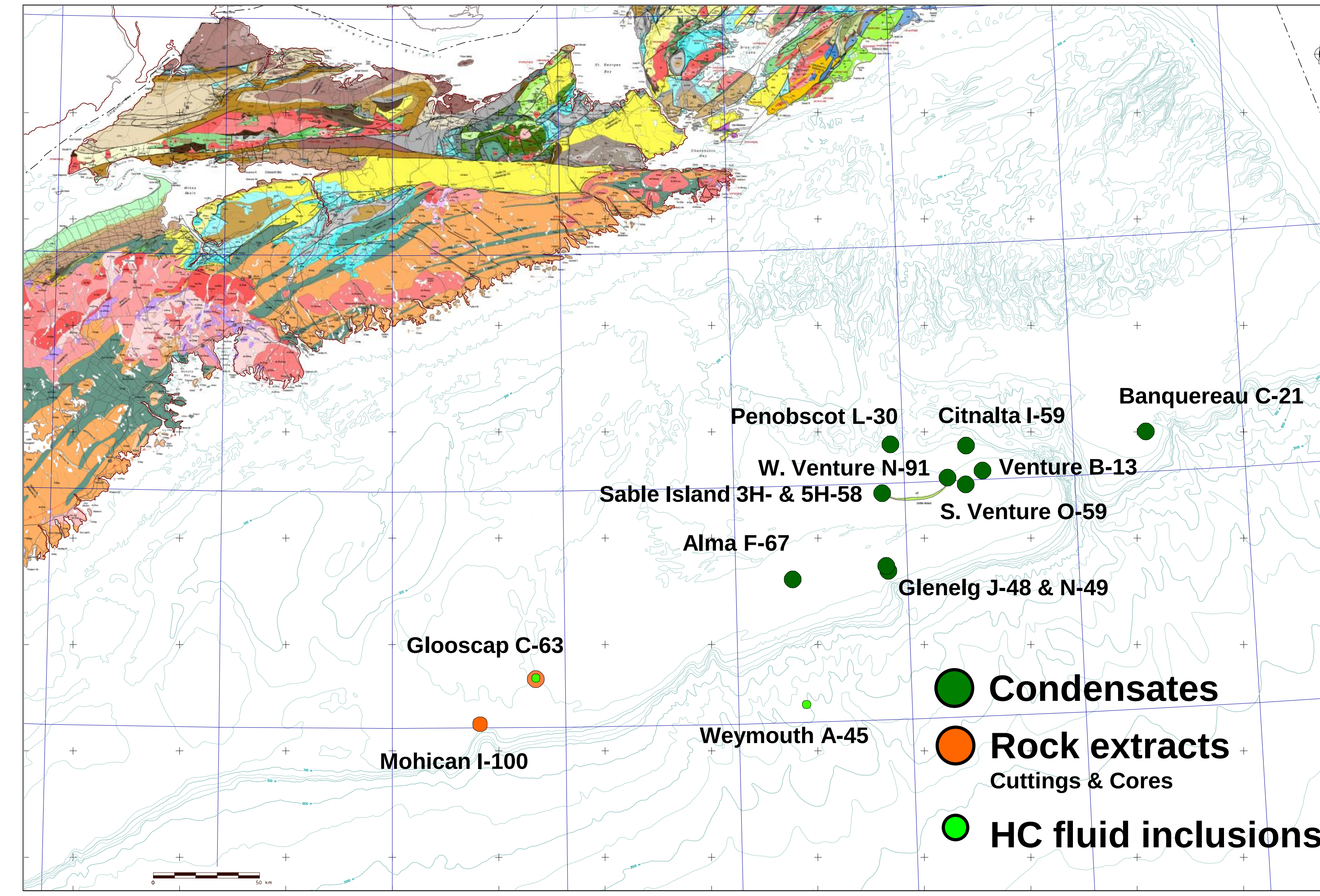
This selection of data, as an example, shows that there is a relatively narrow spread of the maturity gradient throughout the Nova Scotia margin. In wells with several maturity datasets measured by different analysts, there is sometimes convergence of the maturity gradients, which is a confirmation of the validity of the data. Cases of divergence between datasets also exist weakening confidence in either of the datasets. Modeling with the suites of constraints imposed by temperature, pressure, overburden and rifting history inducing the thermal development at the various modeled locations helps distinguishing which one of the maturity gradients applies.

Detailed maturity of each well is neither presented nor discussed in the Petroleum Geochemistry part of the Atlas except for the wells, which serve in identifying the source rocks of the margin in Plates 4-X-X below and Plates X-X-X , Y-Y-Y etc)..

Maturity, however, is used extensively in the modeling part of the study for maturity calibration of the basin models Themis 1D,- 2D and -3D.



OIL, CONDENSATES, ROCK EXTRACTS and FLUID INCLUSIONS DATA



Biomarker analyses of oil and condensates from the following wells:

1. **PENOBSCOT L-30,** RFT#5 2643.00 – 2643.00m, GSC group 1
2. **SABLE 3H-58,** PT#4 1632.20 – 1633.42m, GSC group 3a
3. **SABLE 5H-58E,** DST#4 1639.82 – 1641.65m, GSC not grouped
4. **BANQUEREAU C-21,** DST#2 3585.00 – 3596.00m, GSC group 2
5. **GLENELG J-48,** DST#8 3491.00 – 3495.00m, GSC group 3b
6. **GLENELG N-49,** DST#2 3476.00 – 3485.00m, GSC group 2
7. **GLENELG N-49,** DST#1 3597.00 – 3602.00m, GSC group 2
8. **ALMA F-67,** DST#2 3026.00 – 3032.00 m, GSC not grouped
9. **SOUTH VENTURE O-59,** DST#11 4209.00 – 4217.00 m, Above OP, GSC group 3b
10. **WEST VENTURE C-62,** DST#3 4741.00 – 4743.00 m, Within OP, GSC group 3a
11. **VENTURE B-13,** DST#6 4572.00 – 4579.00 m, Below top OP, Basal Missisauga, GSC group 3b
12. **CITNALTA I-59,** PT#3 12393'-12407' (3777.4-3781.7m), Basal Missisauga
13. **CITNALTA I-59,** PT#2 12964'-12985' (3951.4-3957.8m), Basal Missisauga
14. **CITNALTA I-59,** PT#1 13301'-13317' (4054-4059m), Basal Missisauga
15. **HERON H-73,** DST#6 2294.00 – 2306.00m (South Whale Basin)

Glooscap C-63, cutting extracts from shales interlayered near the top of the Argo Salt at depths:

- Cutting sample 4320-40m
- Cutting sample 4490m

Mohican I-100, extracts of core samples

- Sample 4095.75 m displays a very weak trace
- Sample 4098.14 m displaying oleanane is contaminated

Weymouth A-45. Biomarker analyses of hydrocarbon fluid inclusion from salt canopy:

- Top salt
- Middle salt
- Bottom mix
- Bottom salt

Biomarkers of Oils and Condensates (Hopanes m/z 191)

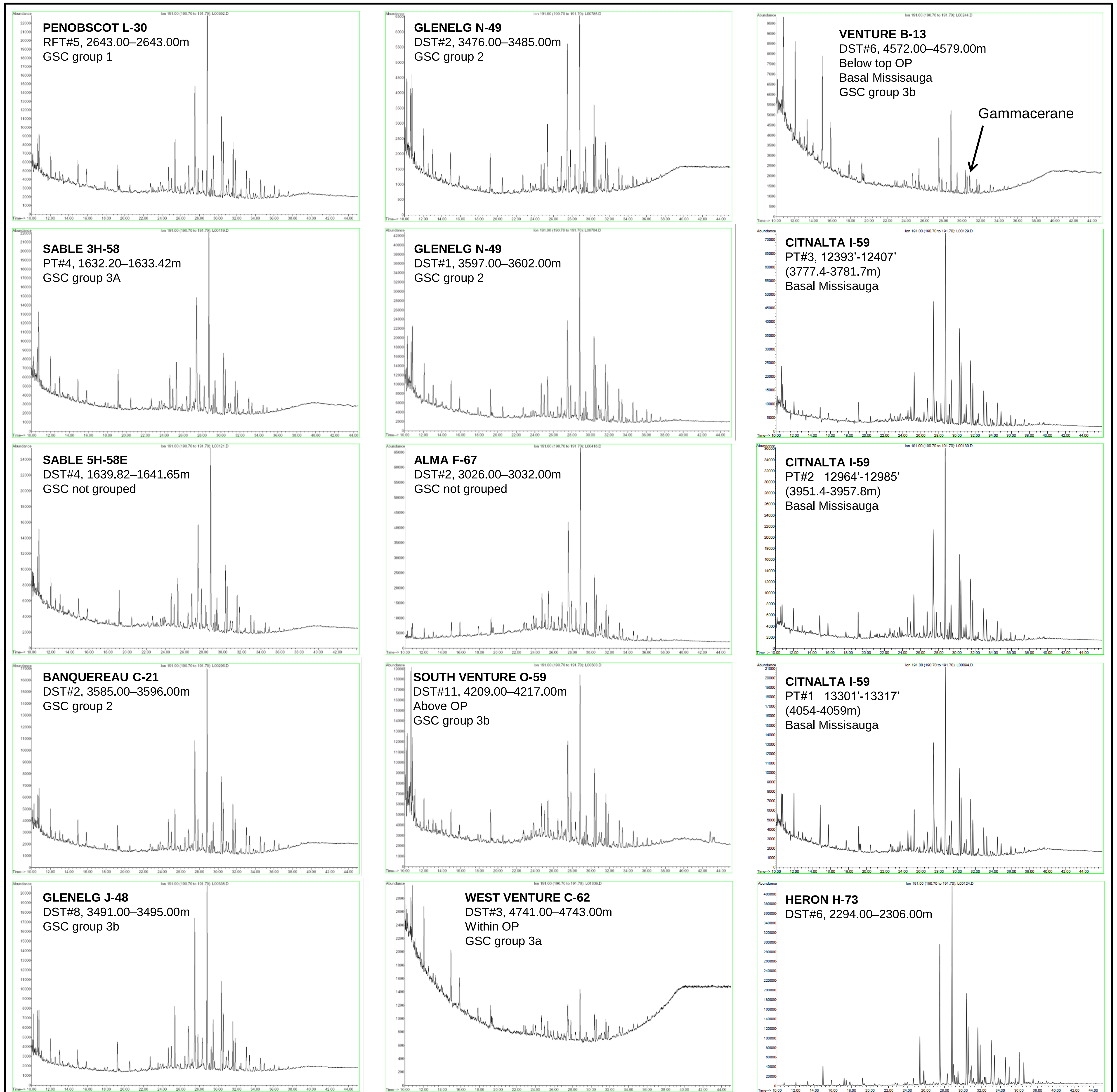


Figure 1: Hopane traces (m/z 191) of 14 condensates and oils from the Nova Scotia margin and 1 from Heron H-73 located in the South Whale Basin of Newfoundland. Among these traces the condensate from DST#6 at Venture B-13 displays a significant Gammacerane anomaly compared to the other oils and condensates. Heron H-73 oil I the South Whale Basin exhibits a slightly improved Gammacerane.

Biomarkers of Cutting Extracts from Venture B-13 (Hopanes m/z 191)

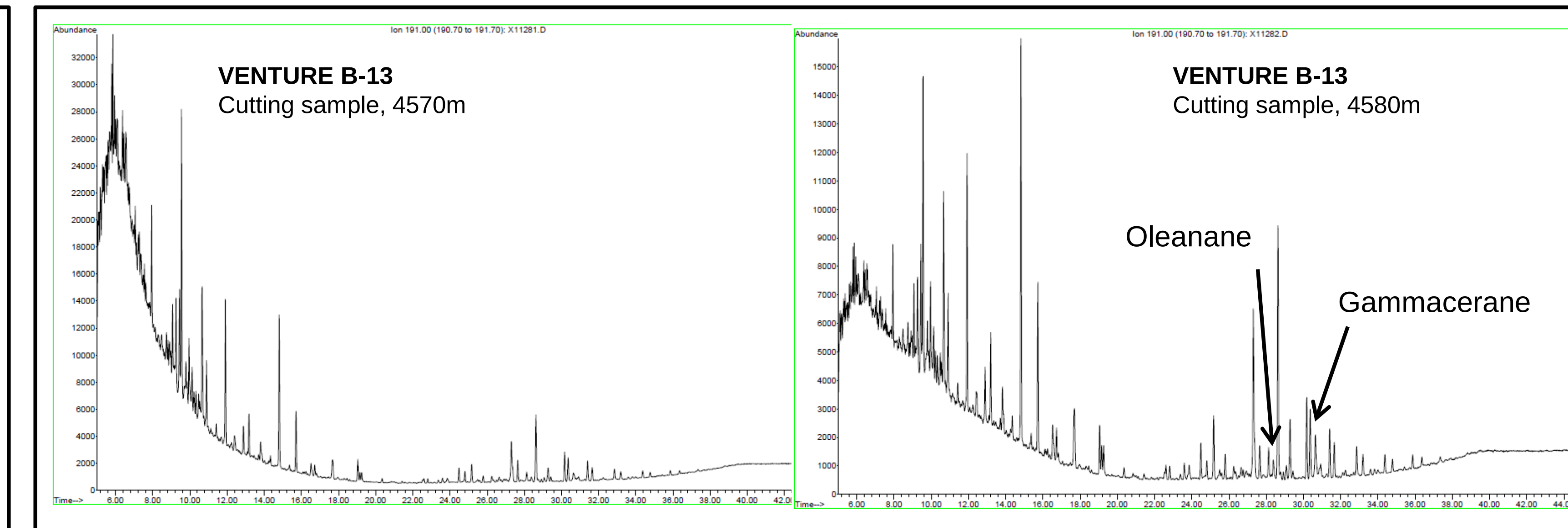


Figure 2: Hopane traces (m/z 191) of 2 cutting samples at 4570 and 4580m from the Venture B-13 well. At 4580m there is a Gammacerane anomaly not observed at 4570m.

Top	Bottom	Units	Mud	Mud Additives	Event	Comments
236		M				STRING STUCK IN THE HOLE - AN OUTSIDE STRING WAS RUN AND CLEANED OUT 21 M OF FILL ON TOP OF BIT
3058		M			FISH	PIPE PARTED AT 1112 M - FISH RECOVERED WITH AN OVERSHOT
5368		M				DRILL PIPE STUCK AFTER CONTROLLING KICK - FISH BACKED OFF & LEFT IN THE HOLE - WELL WAS SUSPENDED
5368		M			KICK	MUD WEIGHT INCREASED TO 2160 KG/M3 TO KILL THE WELL
4673		M			LOST CIRC	RETURNS LOST WHILE CIRCULATING AFTER RUNNING 244 MM CASING
58.5	1295.4	M	SEAWATER - BENTONITE PILLS			
1295.4	2992.4	M	SEAWATER - POLYMER		MUD	
2992.4	5368	M	FRESHWATER - LIGNOSULFONATE			

Figure 3: Mud-scheme used in the Venture B-13. Lignosulfonate was added to the mud 2992 to 5368m. In other well drilled with lignosulfonate mud-additive, there was no Gammacerane contamination but oleanane, which is the case here.

Gammacerane occurrence in Venture B-13, DST#6 4572-4579m

The surprise from Venture B-13 is the occurrence of Gammacerane in the condensate of DST#6. Gammacerane often interpreted as reflecting a source rock deposited in a hypersaline environment would support an Early Jurassic or Triassic (Argo Salt) source rock on the Nova Scotia margin. The arguments for this are:

- Oils from Morocco known to originate from the Toarcian source rock contain Gammacerane (see Plate ***).
- Pliensbachian shale of the Peniche Basin of Portugal contains Gammacerane (see Plate ***).
- Also, deposition of a source rock in a hypersaline environment on the Nova Scotia margin most likely develops in Triassic or Early Jurassic time during or soon after Argo Salt deposition.

These arguments support Early Jurassic sourcing.

Cutting samples from shales interlayered in the Argo Salt (Triassic) in the Glooscap C-63 well were analyzed by Rock Eval pyrolysis to test the hypothesis of Triassic sourcing. The Glooscap C-63 well is the only one penetrating the Argo salt sufficiently and in "autochthonous" position to carry out that test. High TOC and high S1 values in the depth range from 4320m to 4410m are the result of contamination by mud-additive. GCMS analysis of 2 of these samples shown in Figure 1 of the next Plate 4-**** strongly suggest the presence of mud contaminant.

Because, Gammacerane could also be contamination by gilsonite added to the mud, cutting samples at 4570m and 4580m were extracted and analyzed for biomarkers. The m/z 191 traces of the saturates is shown in Figure 2 of this Plate (above). At 4570m, the trace displays background Gammacerane, whereas at 4580m the trace exhibits improved Gammacerane. This distribution between the 2 samples suggests that at 4570m, that is just before testing, there was no excess of Gammacerane meaning neither contamination nor indigenous anomaly. Excess of Gammacerane occurs only in the sample at the bottom or below the tested interval. This observation argues in favor of indigenous Gammacerane in the condensate of Venture B-13 DST#6.

Oleanane - age specific biomarker not present in sediments before the occurrence of angiosperms on earth (~100Ma) - observed in the sample at 4580m is likely part of the lignosulfonate mud-additive used for drilling at these depths.

Glooscap C-63 – Biomarkers of rock extracts

- Shale interlayered in Argo salt
- No Gammacerane
- Mud-additive contamination

Biomarker traces (m/z 191) - Saturates

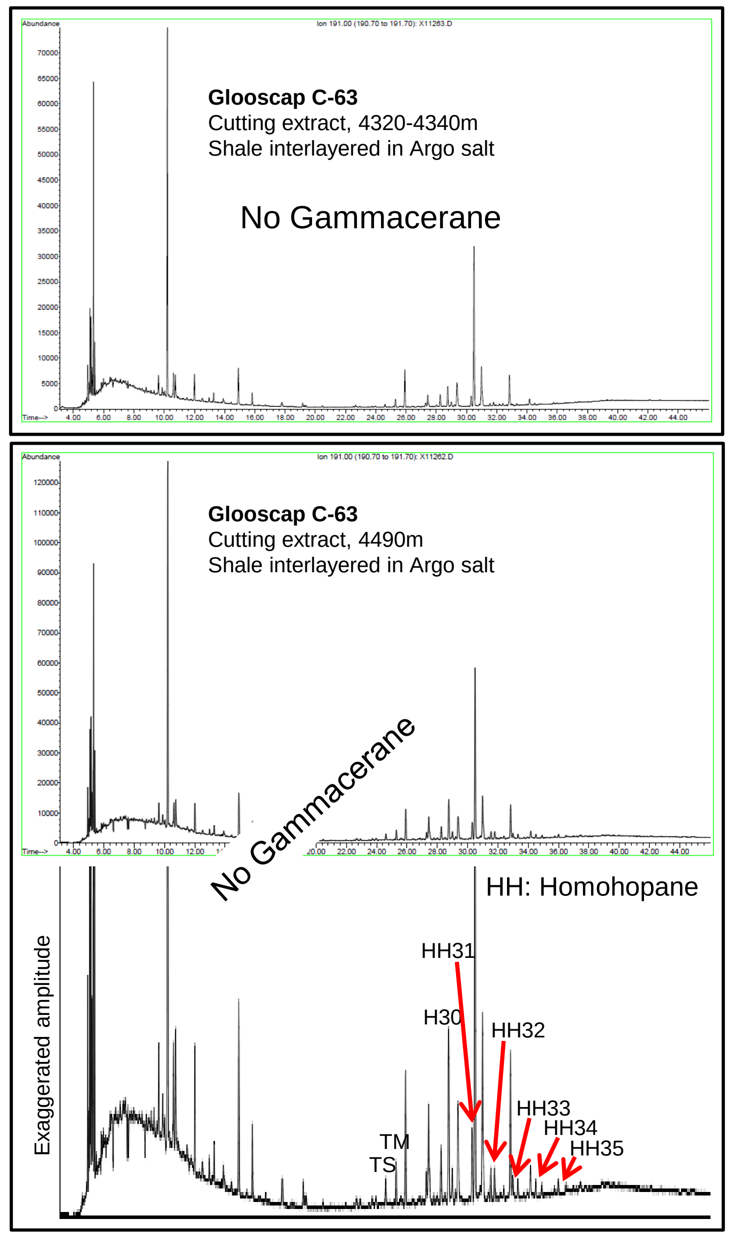


Figure 1: Mud-scheme used in the Glooscap C-63 well. Lignosulphonate was added to the mud 2653 to 4542m.

Top	Bottom	Units	Mud	Mud Additives	Event	Comments
2501.5		M			FISH (1)	PIPE STUCK IN THE HOLE - PUMPED DIESEL, PIPELAX, NUTPLUG - WELL WAS SIDETRACKED (#1) AROUND FISH
2513.7		M			FISH (2)	WELL WAS SIDETRACKED (#2) AROUND FISH
2663.3		M			FISH (3)	DRILL STRING PARTED - BHA RECOVERED WITH AN OVERSHOT
4437		M			FISH (4)	
4541.2		M			FISH (5)	DRILL STRING PARTED - BHA RECOVERED WITH AN OVERSHOT - CONES LEFT ON BOTTOM
4541.2		M			FISH (6)	STRING PARTED WHILE ATTEMPTING TO RECOVER CONES - BHA RECOVERED WITH OVERSHOT
4541.2		M			FISH (7)	STRING PARTED WHILE ATTEMPTING TO RECOVER JUNK - MAGNET LEFT ON BOTTOM & WELL WAS ABANDONED
122	309.7	M	SEAWATER - GEL SWEEPS		MUD	
309.7	847.6	M	SEAWATER WITH BENTONITE	NUTPLUG		
847.6	2653	M	FRESHWATER KCL - POLYMER	NUTPLUG, LIGNOSOL CF, CROMEX, PIPELAX		
2653	4542	M	FRESHWATER - POLYMER - LIGNOSULPHONATE	CROMEX, NUTPLUG, LIGNOSOL, RESINEX, PIPELAX		
2850	3250	M			MUD MOTOR	TURBO DRILLED INTERVAL

Figure 2: Mud-scheme used in the Glooscap C-63 well. Lignosulphonate was added to the mud 2653 to 4542m.

Mohican I-100 – Biomarkers of rock extracts

Mud- additive

Top	Bottom	Units	Mud	Mud Additives	Event	Comments
601	1265	FT	TREATED GEL		MUD	
1265	14410		DLS	SPERSENE, CROMEX		

DLS = Dispersed Lignosulphonate

Biomarker traces (m/z 191) - Saturates

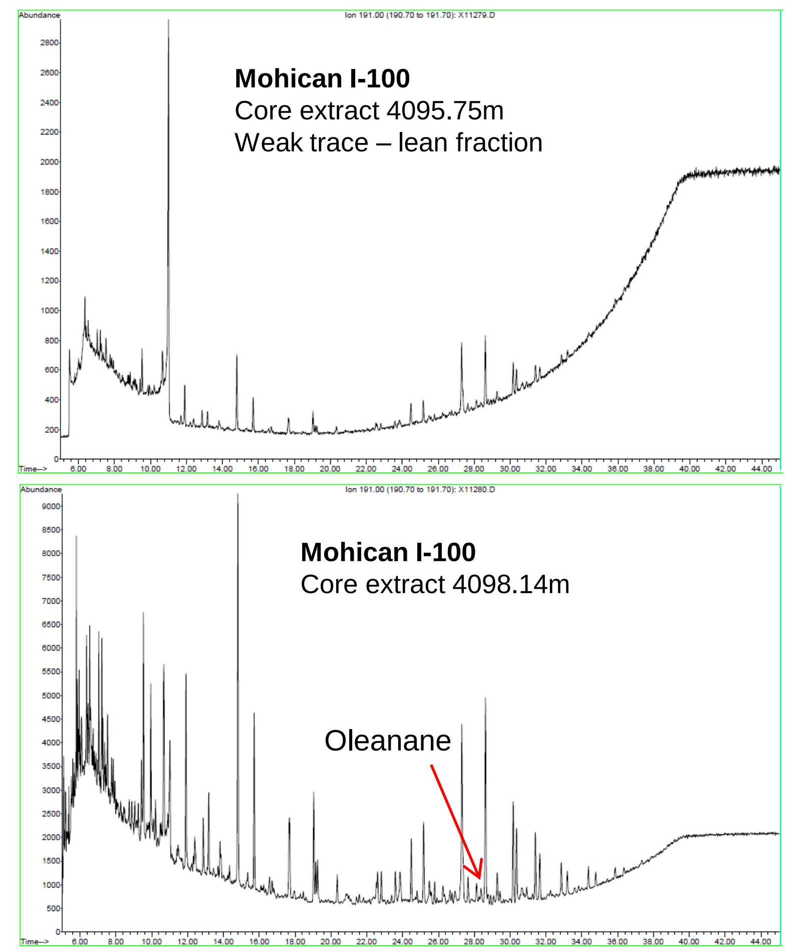
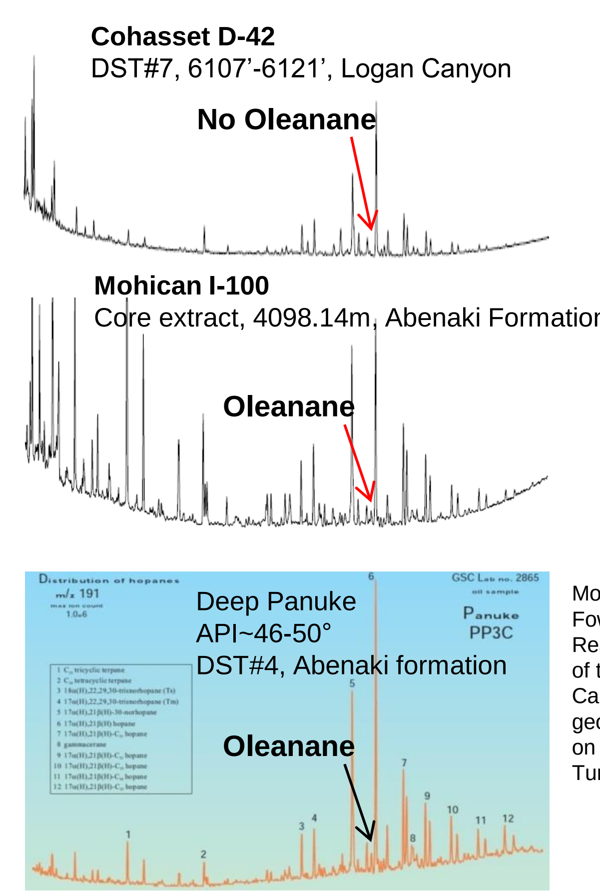


Figure 3: In Mohican I-100, sample from 4095.75 m displays a very weak trace, sample from 4098.14 m displaying oleanane is contaminated



Modified from:
Fowler, M. G. and Obermajer, M. (1999) Reassessing the petroleum geochemistry of the Scotian Shelf, offshore eastern Canada - a cautionary tale for geochemists. 19th International Meeting on Organic Geochemistry, Istanbul, Turkey, September 6-10, 1999, 469-470.

Figure 4: In Cohasset D-42, Mohican I-100 and Deep Panuke (Panuke PP3C), oleanane is present in Jurassic Abenaki oil and stained core extract but absent from Logan Canyon oil. This observation suggests that oleanane - age specific biomarker not present in sediments before the occurrence of angiosperms on earth (~100Ma) – is a mud contaminant.

Biomarker analyses of extracts from the Toarcian source rock, offshore Morocco (IODP Leg 79, Site 547)

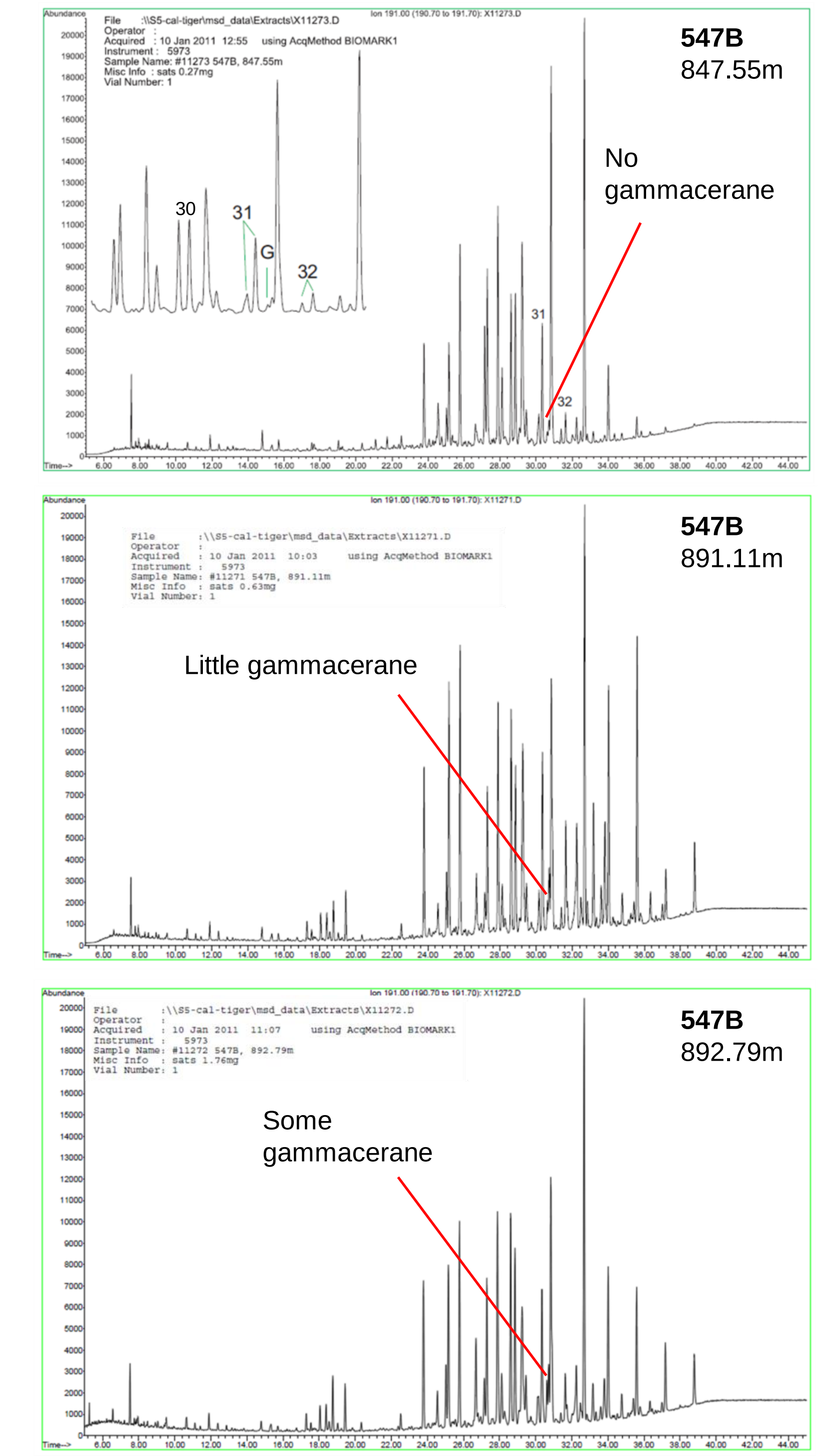


Figure 5: Ion 191 traces of three samples of Toarcian black shales from DSDP Leg 79 Site 547, well 547B. These traces display no or background abundance of gammacerane. The shallow depth of these samples explains their immaturity and unusual signature.

Comments on these data

- ✓ No or lean amount of Gammacerane in these oils and condensates indicates that they were not generated by source rocks deposited under hypersaline (or stratified water) anoxic conditions. For the extracts, the absence or lean presence of Gammacerane indicates that either the source intervals extracted were not deposited under hypersaline (or stratified water) anoxic conditions (Figure 5) or, if not source extracts but staining extracts (Figure 3 perhaps), they did not originate from source rocks deposited under hypersaline (or stratified water) anoxic conditions.
- ✓ Cutting samples from shales interlayered in the Argo Salt (Triassic) in the Glooscap C-63 well were analyzed by Rock Eval pyrolysis to test the hypothesis of Triassic sourcing. The Glooscap C-63 well is the only one penetrating the Argo salt sufficiently and in "autochthonous" position to carry out that test. High TOC and high S1 values in the depth range from 4320m to 4410m are the result of contamination by mud-additive. GCMS analysis of 2 of these samples shown in Figure 1 strongly suggest the presence of mud contaminant.
- ✓ Oleanane - age specific biomarker not present in sediments before the occurrence of angiosperms on earth (~100Ma) - observed in the Deep Panuke condensate (Abenaki reservoir) and Mohican I-100(Abenaki core extract (Figure 4), likely reflects contamination by lignosulfonate mud-additive used for drilling at these depths. In the Logan Canyon reservoir of the Cohasset D-42 well, oleanane is likely derived from the Naskapi source rock or grabbed by leaching along the migration path.

These data are discussed in further details in the following Plates

Fluid Inclusions

Biomarker traces (m/z 191) - Saturates

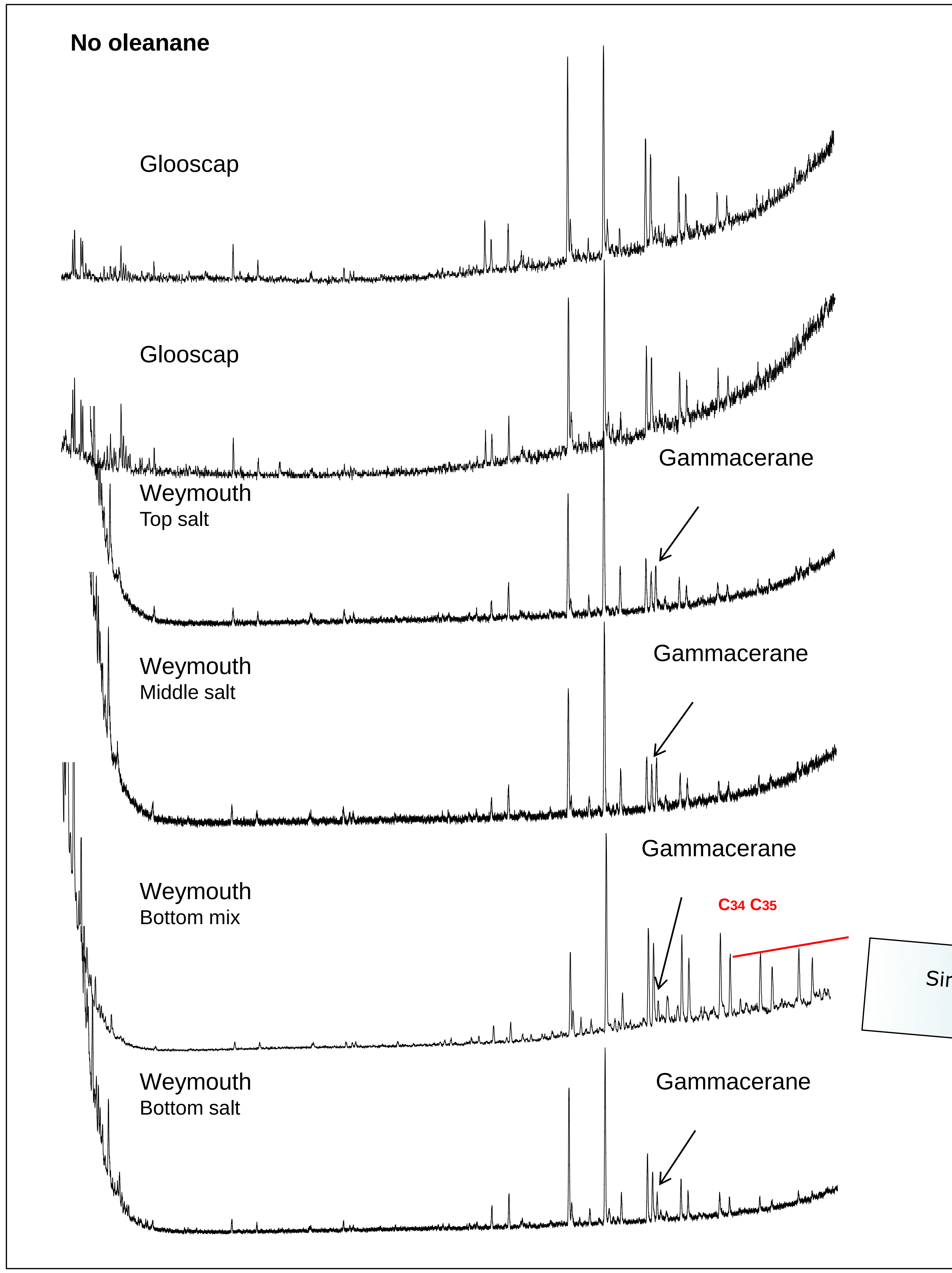
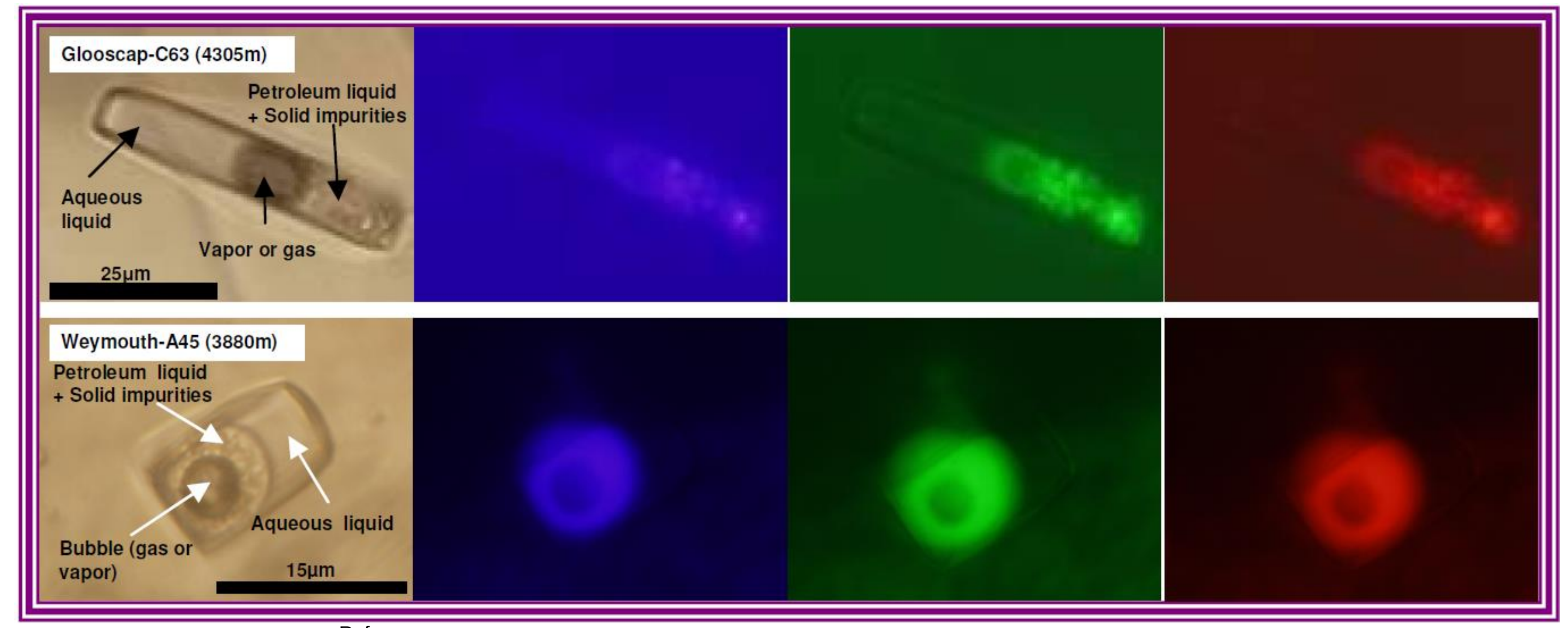
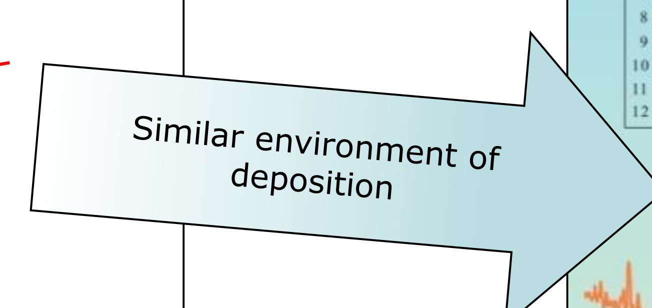


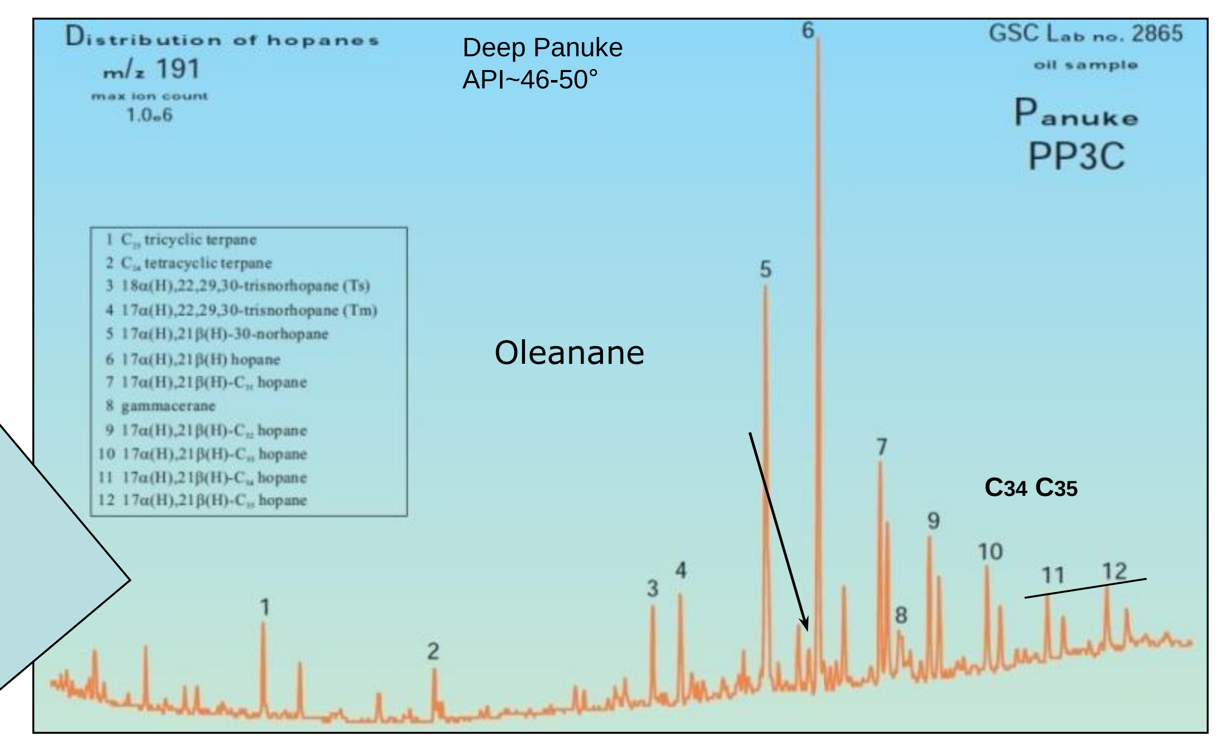
Figure 1: Hopane traces (m/z 191) of hydrocarbon (HC) fluid from inclusions in salt at show significant amount of Gammacerane in the salt canopy at Weymouth A-45. In the autochthonous salt at Glooscap C-63, there is no particular Gammacerane anomaly. In addition, in the Weymouth A-45 bottom mix gathering several samples from the basal part of the canopy, the homohopane ratio C_{35} to C_{34} equal to 1 suggests that the source rock of these HC inclusions deposited in a carbonate environment.



Reference:
Yawooz Kettanah (2010) Hydrocarbon fluid inclusion study in the Argo Salt of Glooscap C-63 and Weymouth A-45 wells, offshore Scotian margin. Study report to OETR.

Figure 2: Example of hydrocarbon fluid inclusions from Kettanah (2010)





Reference:
Fowler, M. G. and Obermajer, M. (1999) Reassessing the petroleum geochemistry of the Scotian Shelf, offshore eastern Canada - a cautionary tale for geochemists. 19th International Meeting on Organic Geochemistry, Istanbul, Turkey, September 6-10, 1999, 469-470.

- **Homohopane ratio C_{35} to C_{34} equal to or greater than 1 is indicative of a source rock deposited in a carbonate environment. This is the case for hydrocarbon fluid inclusions in Weymouth A-45 and in condensate at the "deep Panuke" PP3C well. This environment is compatible with or without hypersaline conditions suggested by presence or quasi absence of Gammacerane, in Weymouth or "deep Panuke", respectively.**
- **Oleanane in "deep Panuke" suggests either contamination (oil-based mud) or leaching of Upper Cretaceous organic matter along the migration path. In the structural position of The Panuke PP3C well, the latter is very unlikely.**

Figure 3: In Jurassic Abenaki condensate at "deep Panuke" (Panuke PP3C), homohopane ratio C_{35} to C_{34} is equal to 1. Such a ratio is indicative of a source rock deposited in a carbonate environment. Oleanane - age specific biomarker not present in sediments before the occurrence of angiosperms on earth (~100Ma) – is also present in this condensate, suggesting contamination by oil-based mud or, but improbably, leaching of Upper Cretaceous organic matter along the migration path.

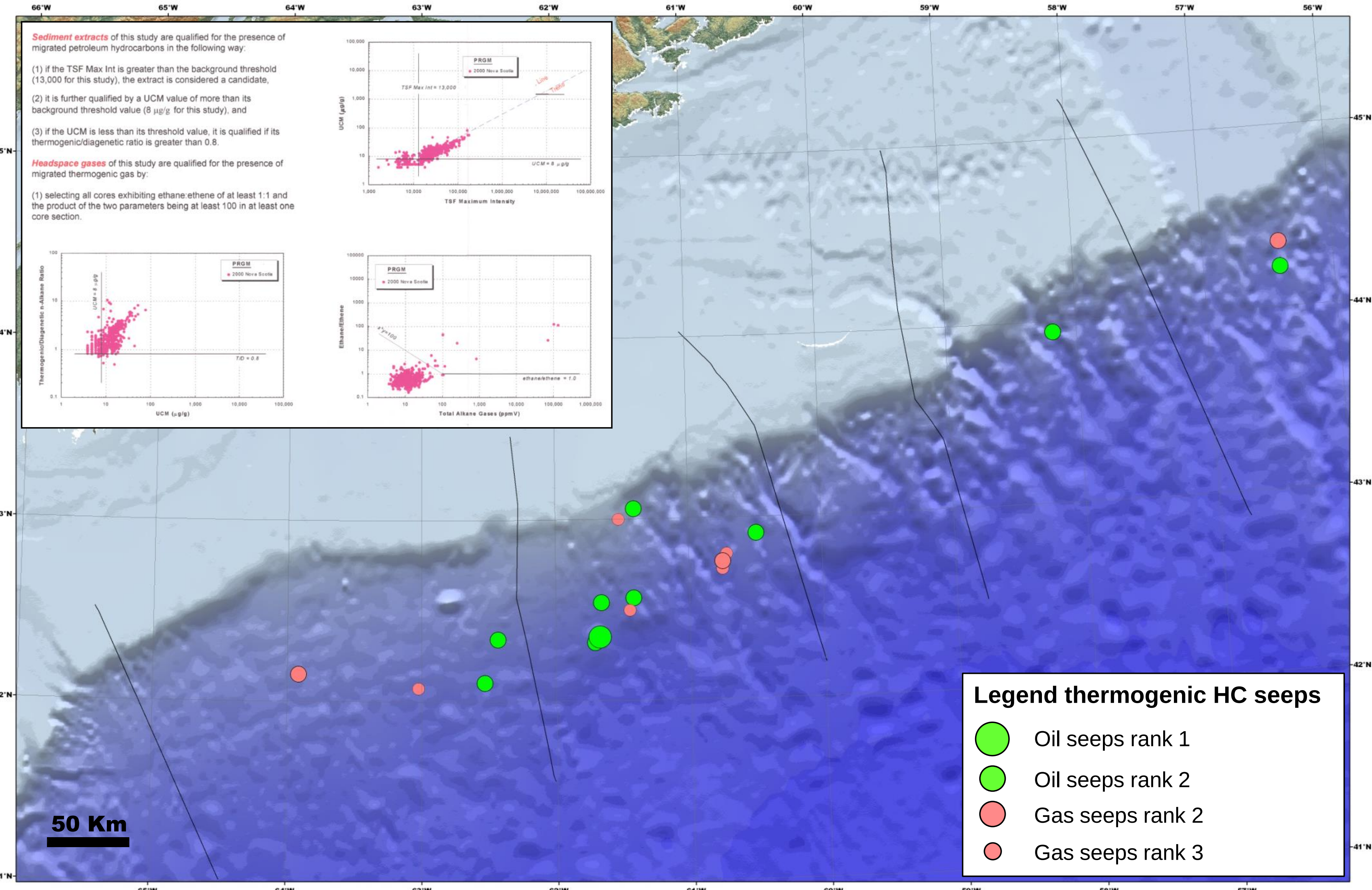


Figure 1: Location of piston-cores seeps displaying thermogenic hydrocarbons in order of importance. Map modified from TDI Brooks Int'l report (2000)

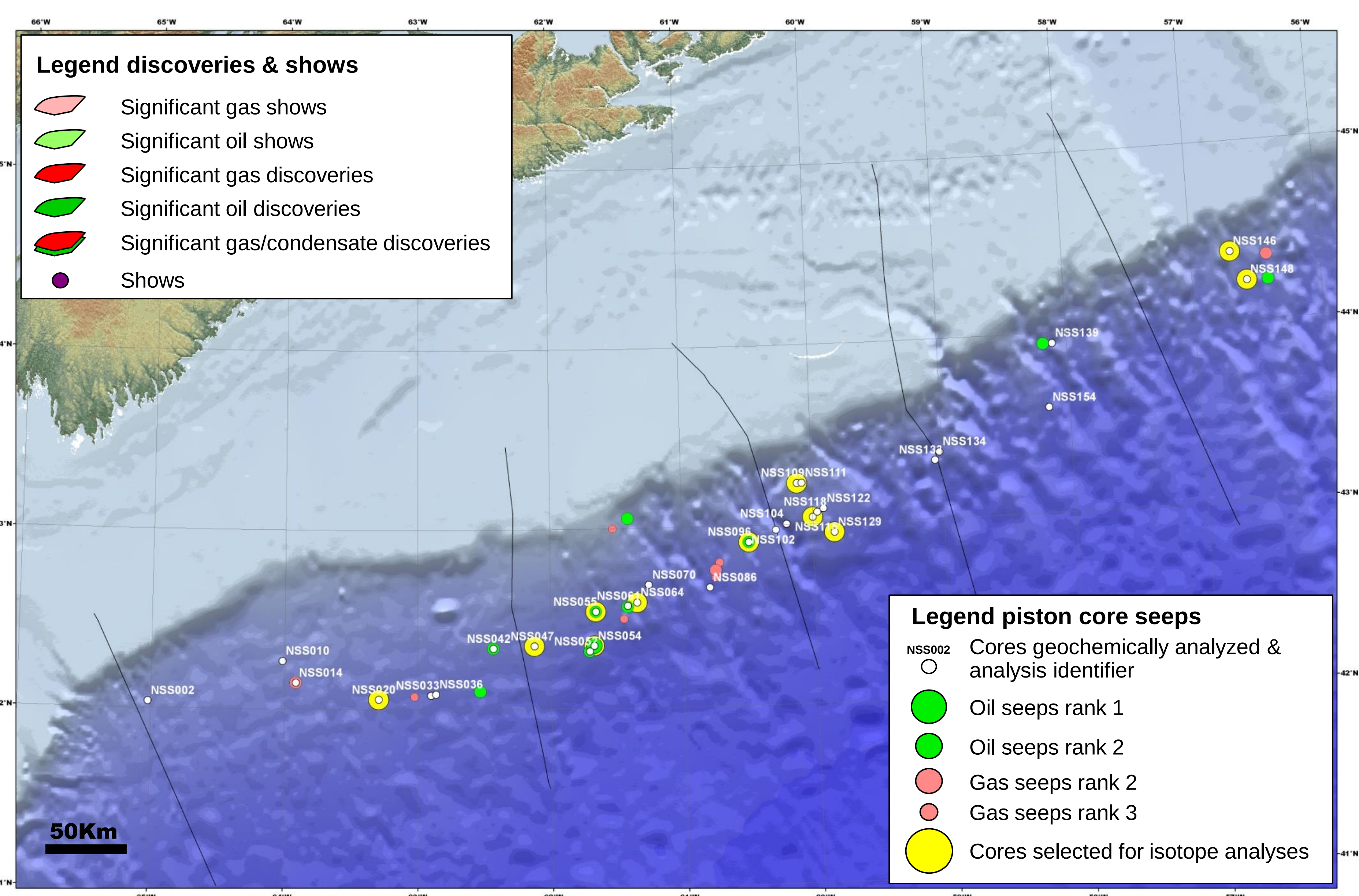


Figure 2: Piston-cores seeps displaying thermogenic hydrocarbons in order of importance and piston-cores geochemically analyzed (numbered). Piston-cores selected for carbon isotopes analyses are the yellow dot. Sample numbering for Map modified from TDI Brooks Int'l report (2000).

REGIONAL GEOCHEMICAL SURVEY for 2000 Nova Scotia Consortium SGE PROGRAM by TDI-Brooks International, Inc.

The report describes first the field and laboratory procedures. Surface geochemical exploration using piston cores are presented by Peters et al. (2004)

The results of standard analyses of the surface geochemical exploration analyses consist of the following:

- Total Scanning Fluorescence,
- C_{15+} hydrocarbons and UCM (Unresolved Complex Mixture),
- Headspace gas, and
- Carbon isotopic composition of gas

Figure 1 shows distribution and rank of significant thermogenic hydrocarbon seeps based on the above mentioned analyses.

Carbon isotopic composition of headspace gas on 2 cores only produced $\delta^{13}C_1$ results. They are:

- Core# NSS014 - 2 sections of the core had enough headspace gas for performing the analyses. Methane $\delta^{13}C_1$ values of -92.50 and 87.66 per mil indicate a biogenic origin of the gas
- Core# NSS057 - 1 section only was measurable producing a $\delta^{13}C_1$ =-28.25 per mil, which falls in the range of thermogenic non-associated gas.

Both seeps did not reach the rank of significant occurrence according to the ranking criteria.

A second part of the report consists of a detailed geochemical study carried out by Geomark Research, Inc. on 30 piston-core samples for TDI-Brooks International, Inc.. Sample preparation and analyses are the followings :

- Bitumen extraction,
- Fraction separation by liquid chromatography,
- GC analysis of the saturate and aromatic fractions,
- GC-MS analysis of the saturate and aromatic fractions
- Carbon isotope analyses of the saturate and aromatic fractions

The data are listed in the Table 1 (below)

Only the isotope data are reinterpreted because the opportunity arose to integrate them with isotope data from Morocco. The biomarker data, in particular the m/z 191 traces do not show any significant abundance of Gammacerane, which suggests that the seeps must originate from a "normal" marine source rock. The other biomarker data of this Table are not subject to reinterpretation because they are not compatible with the other data used in this study. Also, the biomarker interpretation made in the TDI-Brooks International, Inc. report consists only of general considerations are not worth discussions as it is in no related to expressing the possibility of Early Jurassic sourcing of the seeps.

												Terpanes			Steranes Steranes abb mz 218						
#	Sample ID	Core	Lat	Long	Section	TSFmax	EOM ppm	δ13Csat	δ13Caro	Pr/Ph	C19/C23	C24/C23	C29/H	S/T	%C27	%C28	%C29	C28/C29	C27Ts/Tm	C29Ts/Tm	TAS3
1	NSCP0006	NSS002	42.0372	-65.0222	20	2I.815	50	n/a	-27.40		0.04	0.65	0.63	0.27	29.7	25.70	44.60	0.58	0.42	0.25	
2	NSCP0029	NSS010	42.2693	-64.0159	20	27.965	105	-29.68	-28.25												0.14
3	NSCP0040	NSS014	42.1484	-63.9154	11	58.240	110	-29.85	-28.11		0.11	0.53	0.64	0.20	30.8	19.20	50.00	0.38	0.33	0.20	0.05
4	NSCP0059	NSS020	42.0564	-63.2919	16	93.820	90	-30.47	-29.87	1.42	0.10	0.54	0.57	0.41	28.7	20.2	51.10	0.40	0.71	0.37	0.18
5	NSCP0098	NSS033	42.0796	-62.9019	15	48.020	126	-30.20	-29.75		0.08	0.49	0.56	0.38	29.6	20	50.40	0.40	0.5	0.28	0.18
6	NSCP0108	NSS036	42.0858	-62.8644	18	40.070	114	-30.66	-29.55		0.05	0.56	0.56	0.34	28.3	18.90	52.80	0.36	0.51	0.27	0.15
7	NSCP0126	NSS042	42.3388	-62.4321	23	50.380	48	-28.36	-28.74		0.03	0.62	0.55	0.34	27.1	20.60	52.30	0.39	0.46	0.32	
8	NSCP0141	NSS047	42.3511	-62.1239	26	112.340	78	-30.08	-29.46	1.47	0.05	0.55	0.57	0.45	29.5	20.20	50.40	0.40	0.63	0.36	0.11
9	NSCP0156	NSS052	42.3189	-61.7066	27	82.420	70	-29.78	-28.20		0.02	0.57	0.61	0.38	26.5	24.20	49.30	0.49	0.48	0.29	0.09
10	NSCP0162	NSS054	42.3498	-62.6721	12	144.750	88	-30.44	-29.72	1.55	0.10	0.49	0.67	0.43	32.4	17.60	50.00	0.35	0.77	0.38	0.09
11	NSCP0165	NSS055	42.5395	-61.6573	25	124.710	78	-30.26	-29.66	1.42	0.10	0.49	0.57	0.43	28.2	18.40	53.40	0.34	0.73	0.34	0.10
12	NSCP0182	NSS061	42.5693	-61.4155	20	43.260	60	n/a	-29.26	1.56	0.03	0.62	0.62	0.34	24.5	10.4	55.10	0.19	0.51	0.21	
13	NSCP0191	NSS064	42.5883	-61.3455	16	105.600	70	-30.23	-29.42	I.47	0.02	0.53	0.58	0.45	28.1	20.2	51.80	0.39	0.74	0.39	0.07
14	NSCP0208	NSS070	42.6844	-61.2547	6	67.650	68	-30.09	-29.62		0.07	0.38	0.53	0.42	30.6	21	48.40	0.43	0.64	0.35	0.05
15	NSCP0257	NSS086	42.6625	-60.7927	20	60.120	38	-29.20	-28.66		0.02	0.60	0.63	0.39	26.8	25.00	48.20	0.52	0.52	0.30	0.09
16	NSCP0302	NSS096	42.909438	-60.489672	8	109.620	175	-30.50	-29.68	1.39	0.11	0.54	0.57	0.48	27.1	21.1	51.70	0.41	0.63	0.37	0.11
17	NSCP0320	NSS102	42.973267	-60.282017	20	68.130	102	-30.48	-29.57		0.04	0.66	0.61	0.40	24.4	28.1	47.50	0.59	0.47	0.29	0 13
18	NSCP0326	NSS104	43.004593	-60.199075	20	51.380	93	-30.11	-29.17		0.03	0.62	0.62	0.34	23.8	27.9	48.30	0.58	0.37	0.28	0 12
19	NSCP0341	NSS109	43.230265	-60.113157	11	76.860	120	-30.47	-29.52	1.50	0.09	0.53	0.55	0.52	27.2	19.90	52.90	0.38	0.57	0.38	0.11
20	NSCP0348	NSS111	43.230945	-60.07698	28	54.200	120	-30.23	-29.27		0.10	0.52	0.58	0.39	27.2	22.20	50.60	0.44	0.49	0.32	0.10
21	NSCP0359	NSS115	43.038225	-59.999515	16	82.400	220	-30.57	-29.90	1.35	0.1	0.55	0.54	0.48	27.4	20.60	52.10	0.40	0.81	0.42	0.14
22	NSCP0369	NSS118	43.065698	-59.96357	26	53.640	85	-30.23	-29.68		0.06	0.61	0.58	0.35	24.4	26.70	48.90	0.55	0.39	0.29	0.11
23	NSCP0381	NSS122	43.084255	-59.91686	23	76.960	100	-30.41	-29.76		0.08	0.59	0.58	0.39	23.1	26.7	50.10	0.53	0.51	0.32	0.12
24	NSCP0402	NSS129	42.950465	-59.83766	25	166.350	328	-30.57	-30.04	1.45	0.15	0.56	0.57	0.49	28.5	18.90	52.70	0.36	0.77	0.43	0.14
25	NSCP0414	NSS133	43.3277	-59.051572	26	63.710	102	-30.37	-29.44		0.03	0.53	0.63	0.37	24.3	26.00	49.70	0.52	0.46	0.30	0.07
26	NSCP0417	NSS134	43.37268	-59.015608	20	47.220	95	-30.05	-28.88		0.06	0.58	0.71	0.28	25.8	27.00	47.30	0.57	0.32	0.26	0.12
27	NSCP0429	NSS139	43.942128	-58.11025	15	73.960	135	-30.32	-29.22		0.06	0.53	0.58	0.47	26.7	22.20	51.10	0.43	0.57	0.34	0.11
28	NSCP0448	NSS146	44.385383	-56.691885	11	29.465	42	-29.93	-29.05	1.31	0.05	0.57	0.61	0.67	28.1	23.70	48.20	0.49	0.72	0.39	0.12
29	NSCP0453	NSS148	44.221647	-56.576188	2	28.885	78	-30.63	-29.87	1.23	0.04	0.60	0.62	0.58	30.4	25.80	43.80	0.59	0.69	0.36	0.18
30	NSCP0472	NSS154	43.588087	-58.159307	25	61.020	93	-30.20	-29.90		0.04	0.50	0.66	0.37	24.4	27.00	48.60	0.56	0.42	0.28	0.14

S/T= Steranes/Terpanes
TAS3=(C20+C21)/(ΣC20-C28) m/z=231
ROM=Immature Recent organic matter

Table 1: List of the piston-core samples geochemically analyzed (White dots in Figure 2, right).

Reference:
Bernard B. B., Allan K. A. and McDonald T; J. (2000) Regional geochemical survey for 2000 Nova Scotia Consortium. SGE Program. TDI-Brooks International, Inc. report, December 2000.

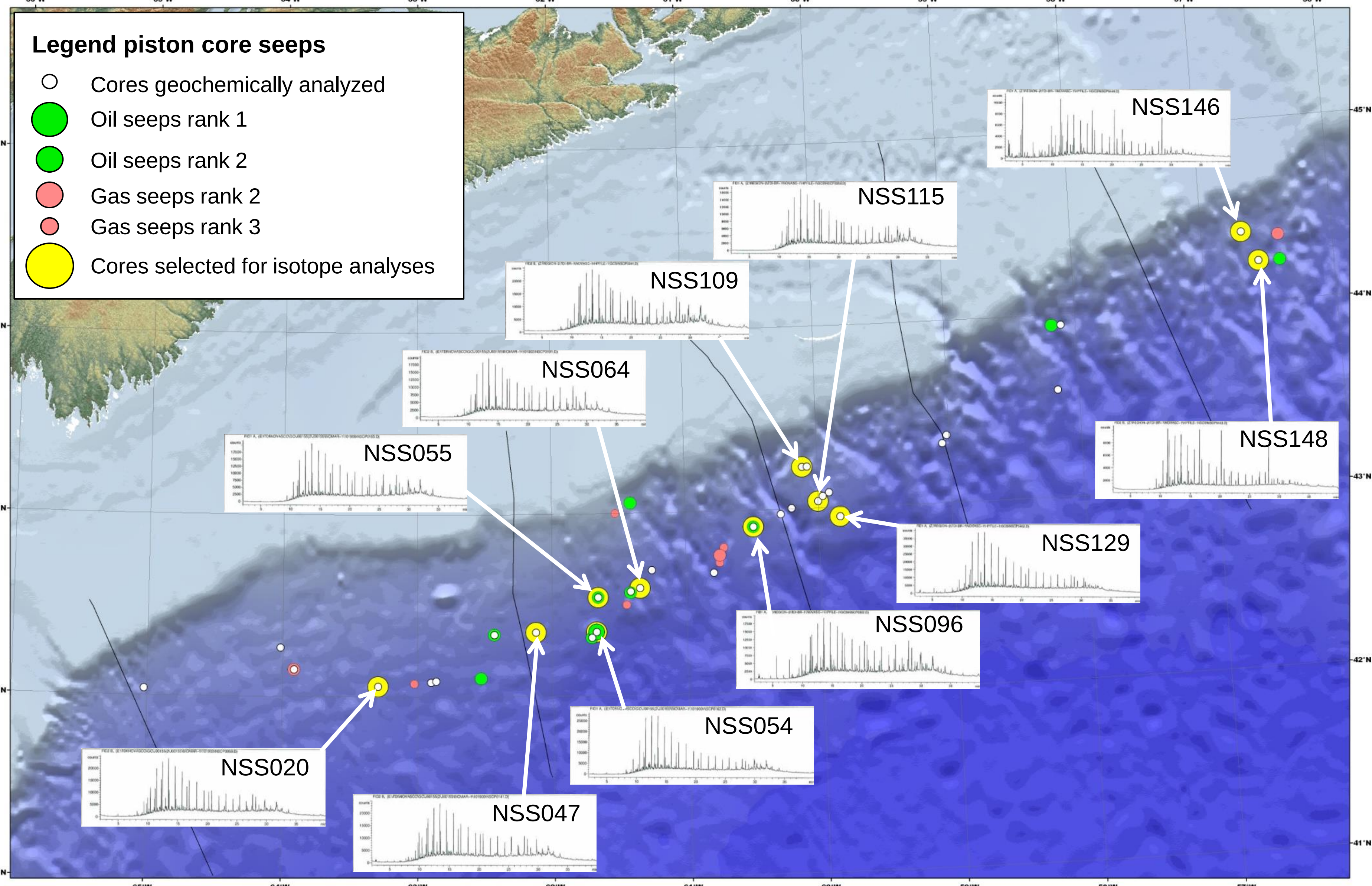


Figure 1: Location of the piston-cores analyzed for carbon isotopes (yellow dots). The gas-chromatograms show that the samples extracted from the piston-cores are as little as possible contaminated by recent indigenous organic material.

Re-interpretation of the "REGIONAL GEOCHEMICAL SURVEY for 2000 Nova Scotia Consortium SGE PROGRAM by TDI-Brooks International, Inc.

Carbon isotope data

This interpretation integrates carbon isotope data of oil/condensate and source rock extracts from Mukhopadhyay (1989 & 1990), and TDI-Brooks data (2000) on seeps from piston-cores and data from Morocco margin graciously provided by Geomark Research, Inc.. Yet many of the extracts do not qualify as source rock for the oil and condensates from the Nova Scotia margin (see Sofer diagram below), some do. Along the Sofer line (Sofer 1984), $\delta^{13}C$ of the source extracts lighter than oil/condensates suggest a lower maturity of the source samples analyzed.

The piston-core seeps displaying $\delta^{13}C$ ranging in the -30 to -31 per mil for the saturate fraction and -29 to -30 per mil for the aromatic fraction are isotopically lighter than the oil/condensate and their qualifying source rocks, indicating a different source rock for these oil-seeps.

Comparison with Morocco oils (see location Figure 2) known to originate from the Toarcian source rock suggests that the piston-core seeps could originate from an Early Jurassic source rock possibly present on the Nova Scotia margin:

- The oil from the Essaouira field of Sidi Rhalem is isotopically compatible with the piston-core seeps (Figure 2)
- The MO-002 oil from the Tarfayat Basin (Cap Juby; see location Figure 2) known to originate from the Toarcian source rock displays isotopic values apparently compatible with the bulk of the Nova Scotia oils and condensates yet its biomarker present characteristics of hypersalinity (gammacerane) of an Early Jurassic (Toarcian) source rock (see Plate *****). However, the MO-002 oil is severely biodegraded, which may be the reason for the drift of its isotopic composition toward heavier values.

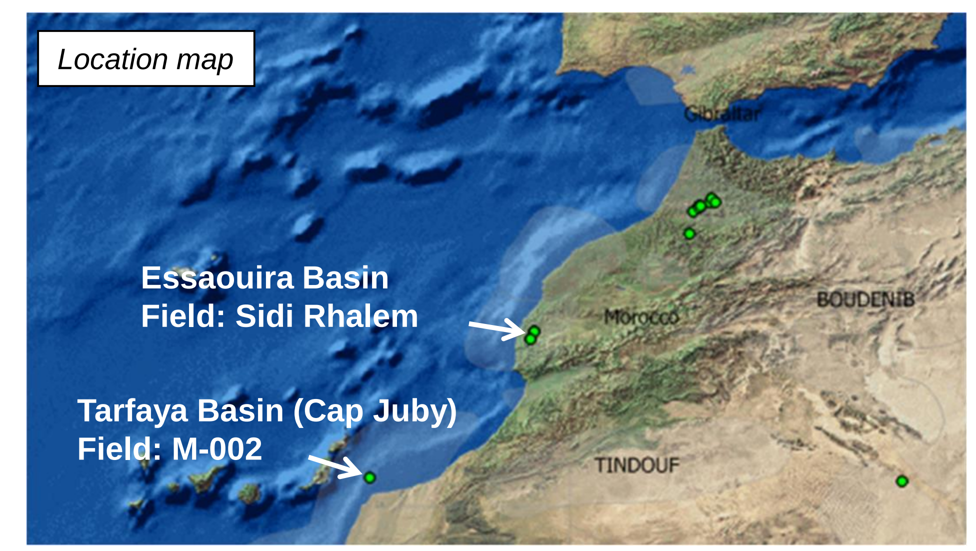


Figure 3: Location of the Morocco oil samples used for comparison of oils and condensates across the Atlantic ocean with the Nova Scotia conjugate margin

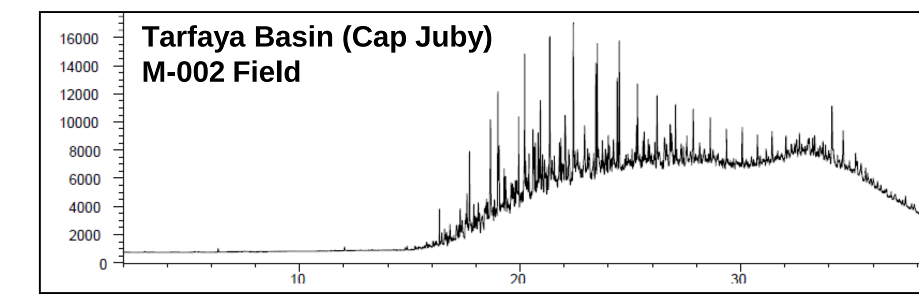


Figure 4: Gas-chromatographic trace of the MO-002 oil (Cap Juby, Tarfayat Basin) showing biodegradation of the oil.

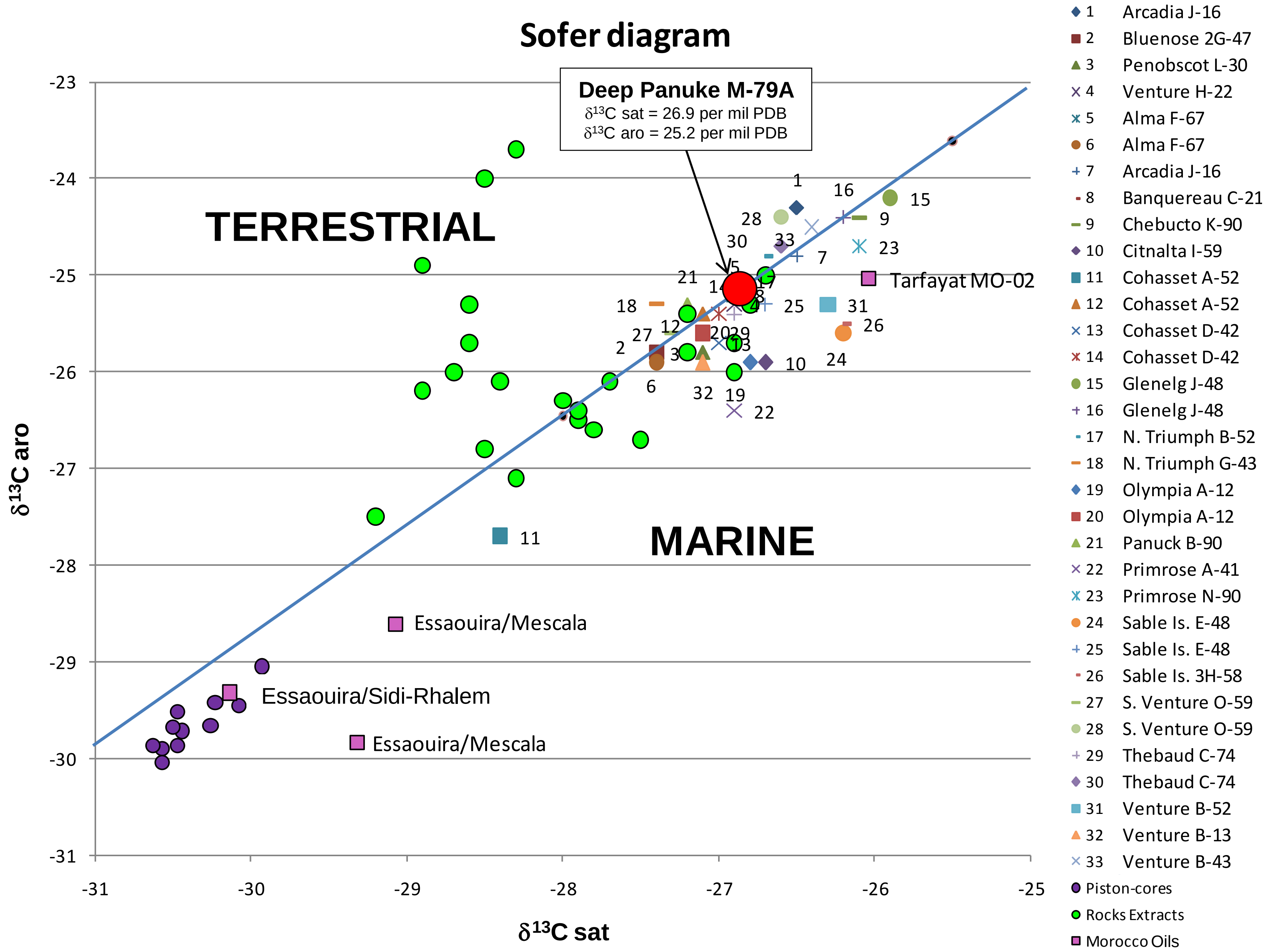


Figure 2: Sofer diagram (Sofer, 1984) displaying carbon isotopes (saturates & aromatics) of oils, condensates (numbered samples) and bitumen extracts from rock samples (green dots) from the Nova Scotia margin reported by Mukhopadayay (1990). Piston-cores seeps (dark blue dots) from TDI-Brooks Int'l, Inc. study (2000) and Morocco oils) communicated graciously by Geomark Research are also included in the diagram. The Most of the Nova Scotia oils en condensates are located near the separation line between terrestrial and marine source origin. The bitumen extracts located near the line are candidates for sourcing the oils and condensates. Other extract located deep in the Terrestrial domain of the diagram can be discarded as source of the Nova Scotia oils and condensates. The piston-core seeps originate from a very distinct source rock. The isotope correlation of the piston-cores with Morocco Sidi Rhalem and Cap Juby MO-02 oils known to be sourced from the Toarcian source rock supports the presence of an Early Jurassic source rock on the Nova Scotia margin (conjugate to the Morocco margin). The MO-02 oil does not plot with the piston-core group but the new data point from Deep Panuke M-79A exhibits a $\delta^{13}C$ aro = 25.2 per mil PDB comparable to MO-02. The difference in saturates could be due to biodegradation of the MO-02 oil.

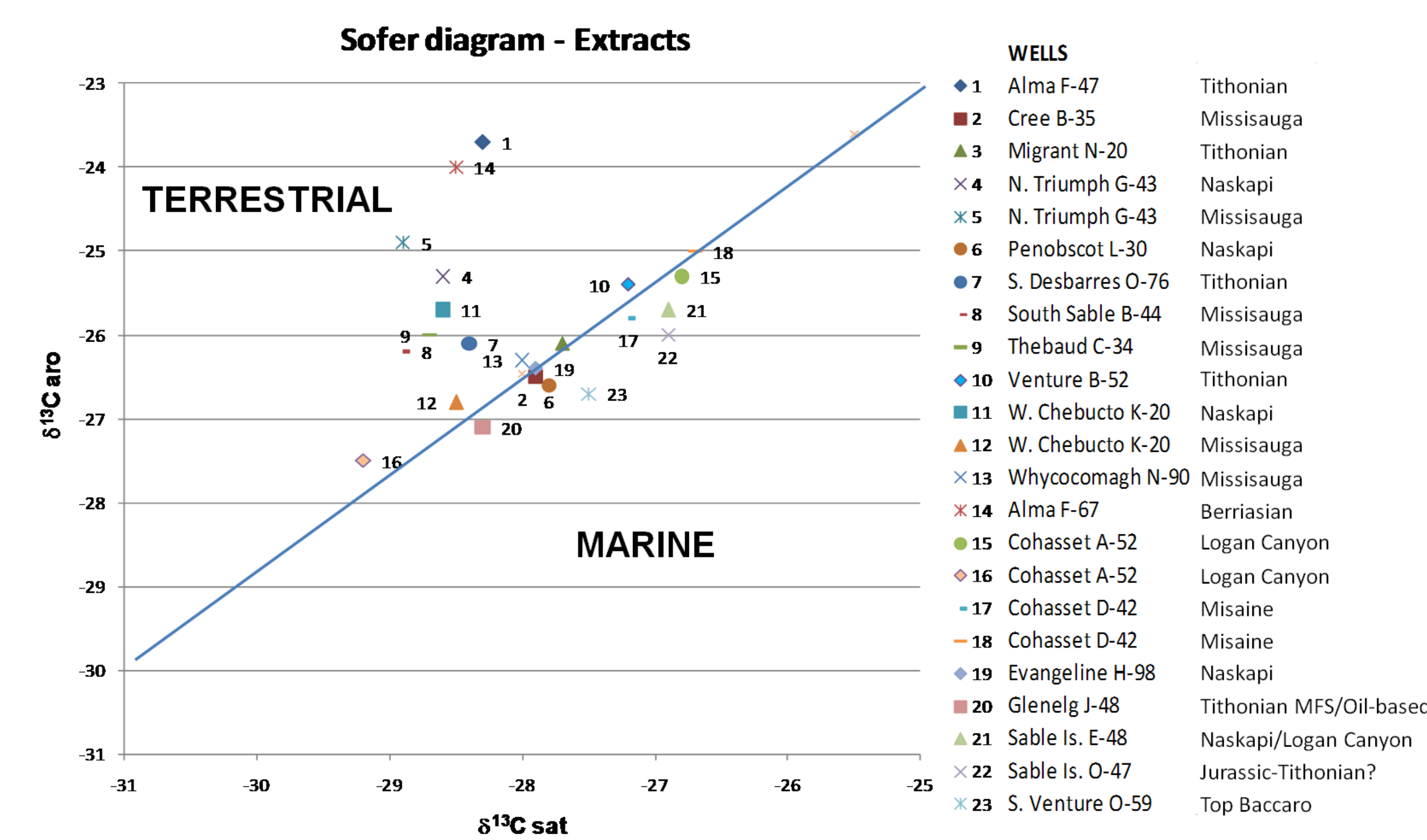


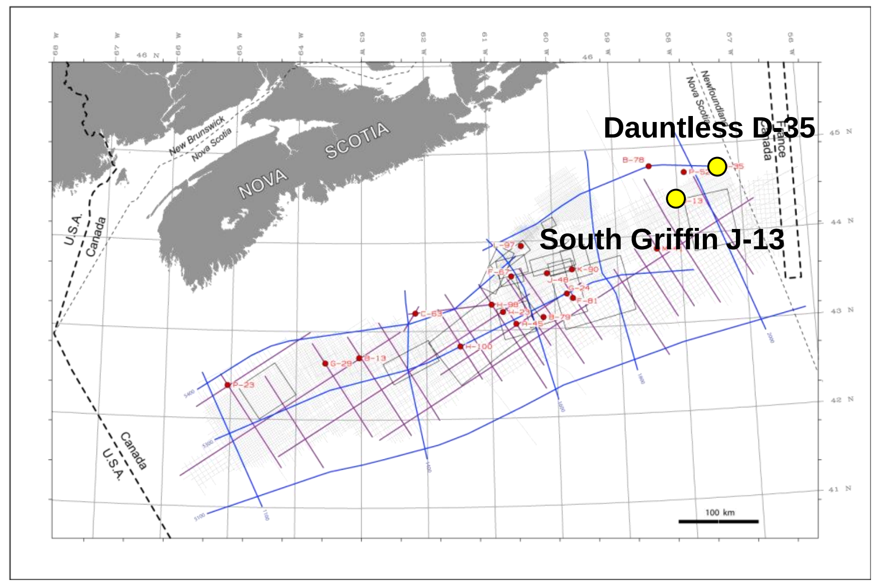
Figure 4: Sofer diagram (Sofer, 1984) displaying carbon isotopes (saturates & aromatics) of bitumen extracts from rock samples (green dots of Figure 2) selected from various wells and stratigraphic intervals. Only the bitumen extracts located near the line are candidates for sourcing the oils and condensates of the Nova Scotia margin.

References:
Mukhopadhyay P. K. 1990 Characterization and maturation of selected oil and condensate samples and correlation with source beds. Report, to Scientific Authority, Jon A. Wade. Bedford Institute of Oceanography. Dartmouth, Nova Scotia
Sofer Z. (1984) Stable carbon isotope compositions of crude oil: application to source depositional environments and petroleum alteration. American Association of Petroleum Geologists Bulletin, 68, 31-49
Bernard B. B., Allan K. A. and McDonald T; J. (2000) Regional geochemical survey for 2000 Nova Scotia Consortium. SGE Program. TDI-Brooks International, Inc. report, December 2000.

Sources Rocks from

PFA 2011 Updated

South Griffin J-13

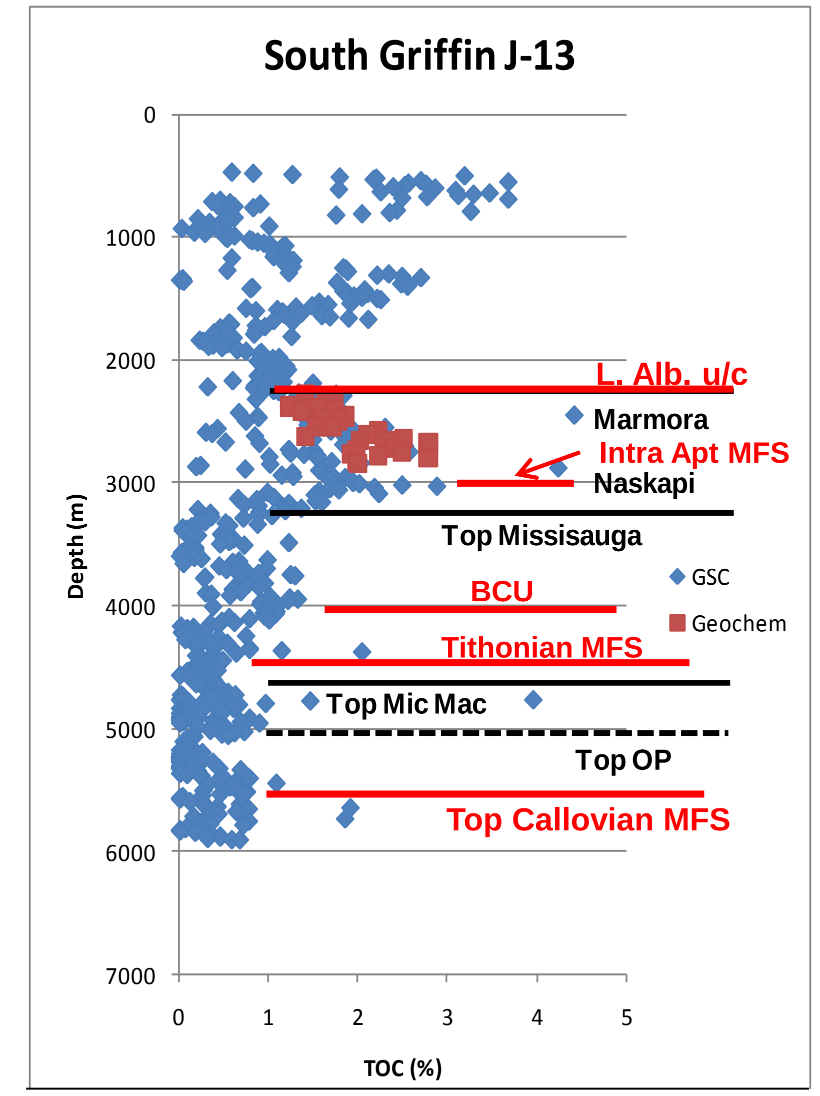


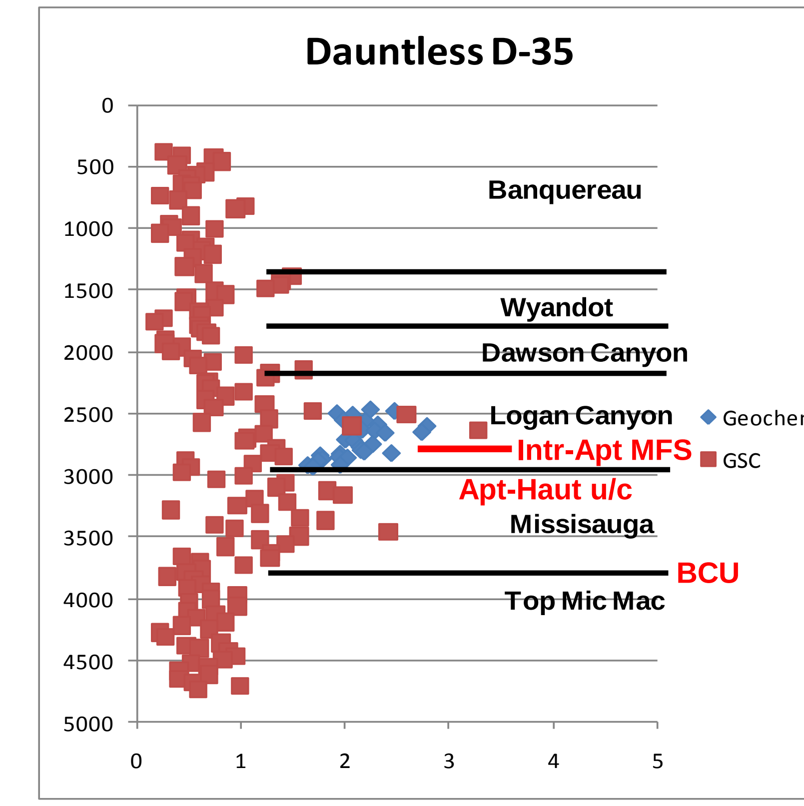
Top	Bottom	Units	Mud	Mud Additives	Event	Comments
924.5		M			FISH	DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
3115.4		M				
4027.7		M				TWO BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
4034.7		M				DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
4120		M				THREE BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
103	342.9	M	SEAWATER		MUD	
342.9	917.5	M	SEAWATER - XCD			
917.5	3115.1	M	SEAWATER - KCL POLYMER			
3115.1	5911.1	M	FRESHWATER - LIGNOSULFONATE	LIGNITE, LIGNOSULFONATE		
3215.9	3258.9	M			MUD MOTOR	TURBO DRILLED INTERVAL
3332.1	3450	M				
4178.5	4181.6	M				
4340	4356.2	M				

Dauntless D-35

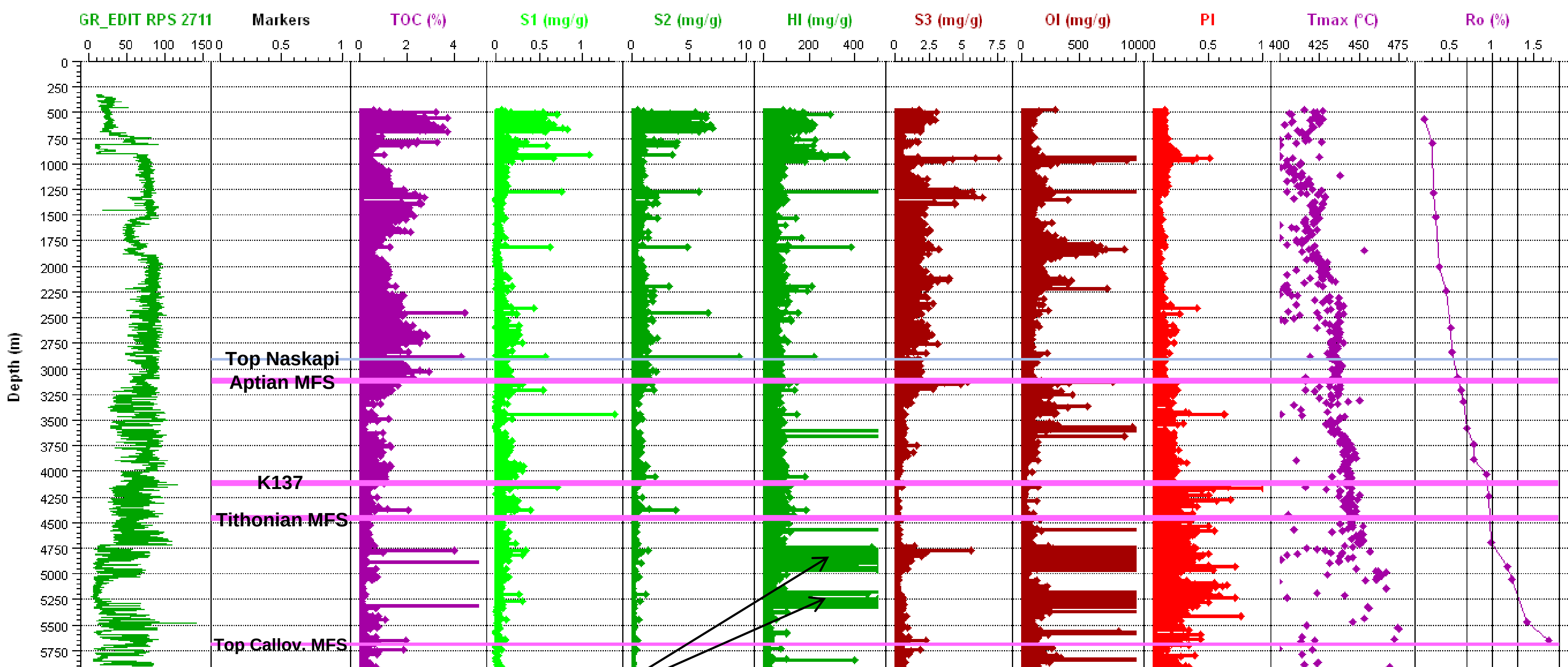
Top	Bottom	Units	Mud	Mud Additives	Event	Comments
2830		FT		STUCK CASING PULLED FREE	FISH	
330	1001	FT	TREATED GEL		MUD	
1001	15555	FT	DLS	SPERSENE, CROMEX, DIESEL, PIPELAX		

DLS = Dispersed Lignosulphonate

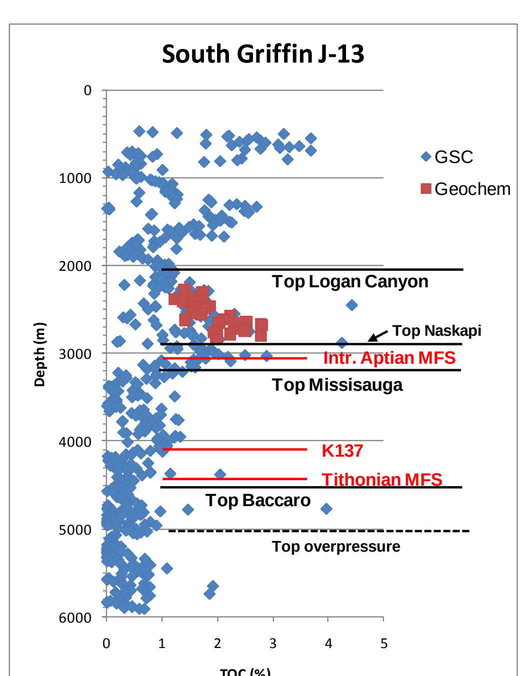


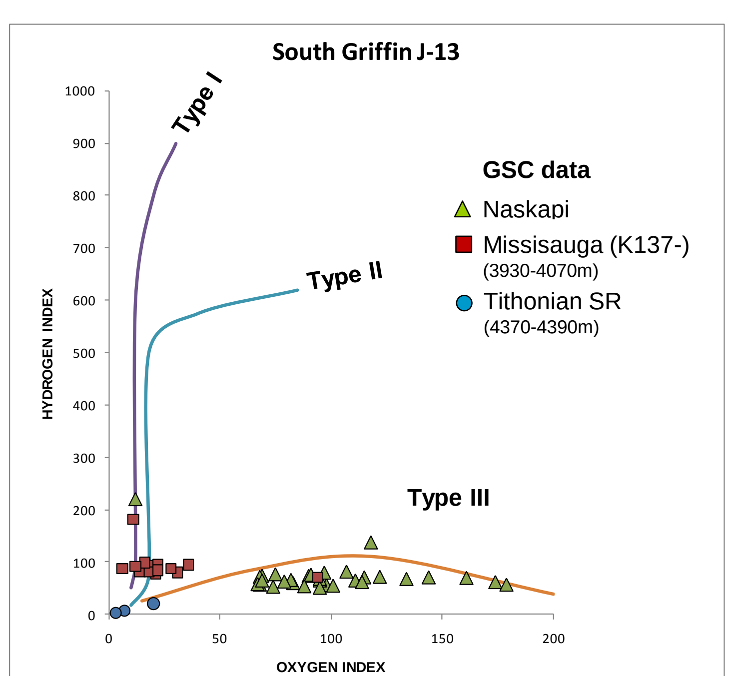


Like South Griffin J-13, Dauntless D-35 was drilled using Lignosulfonate added to the mud



The large Hydrogen and Oxygen Indices below 3115m down to TD reflect contamination by mud additive (Lignosulfonate). Below the Tithonian MFS, HI values are too high for the elevate level maturity of that section of the well.



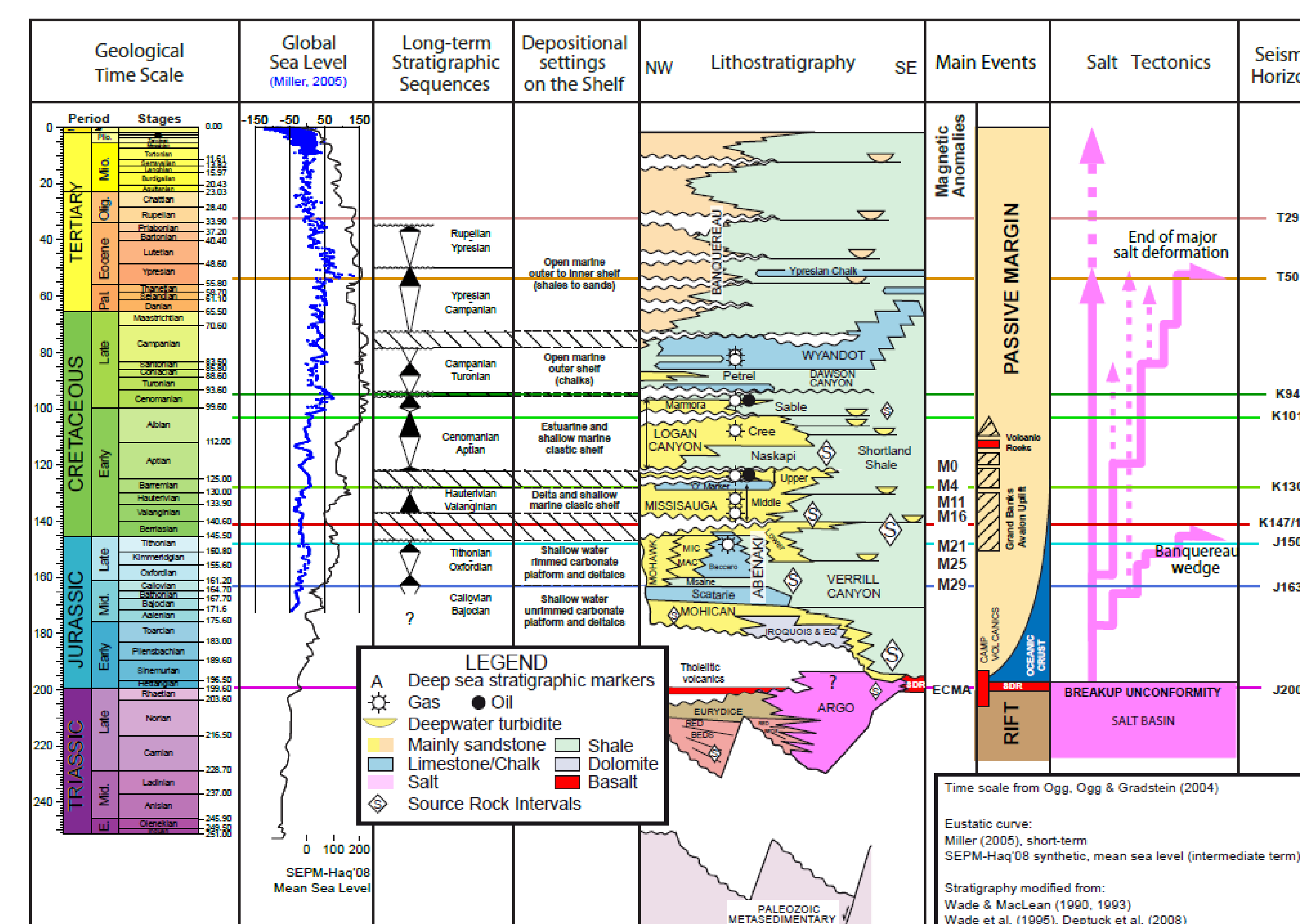


The Naskapi source rock is well exemplified in South Griffin J-13

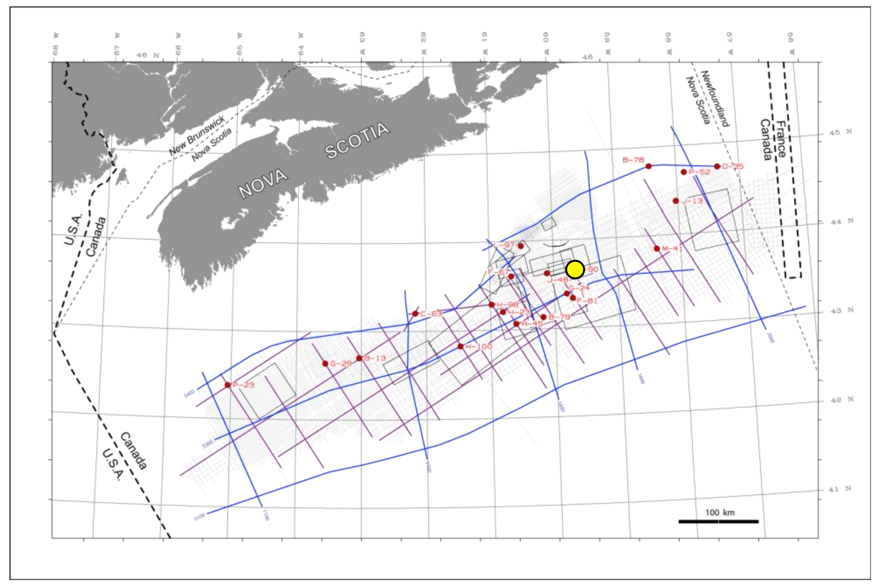
- ✓ Maximum TOC are slightly greater than 2%
- ✓ Hydrogen and Oxygen Indices (HI & OI, respectively) indicate a Type III kerogen at best (see HI x OI diagram, left)
- ✓ Vitrinite Reflectance Ro=0.5 to 0.6% indicate incipient maturity only
- ✓ Eastward, the Naskapi source rock is present in Dauntless D-35
- ✓ For modeling purpose, the following characteristics were retained:
  - TOC=2%
  - Kerogen Type III

NOTE:

- ✓ TOC=2% at the level of the Tithonian MFS with HI and OI values indicating an exhausted source rock
- ✓ TOC=2% at the level of the Callovian MFS
- ✓ The Missisauga formation above the BCU unconformity displays TOC averaging less than1% in South Griffin J-13 and 1.5% in Dauntless D-35
- ✓ The Logan Canyon formation is also organic-rich in both South Griffin J-13 and Dauntless D-35 but remains immature in these two wells and throughout the margin

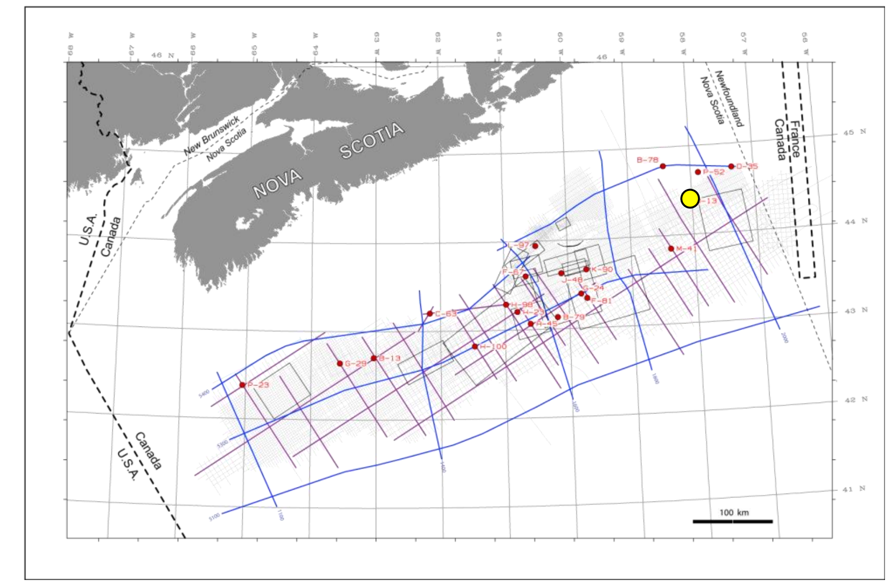


Annapolis G-24

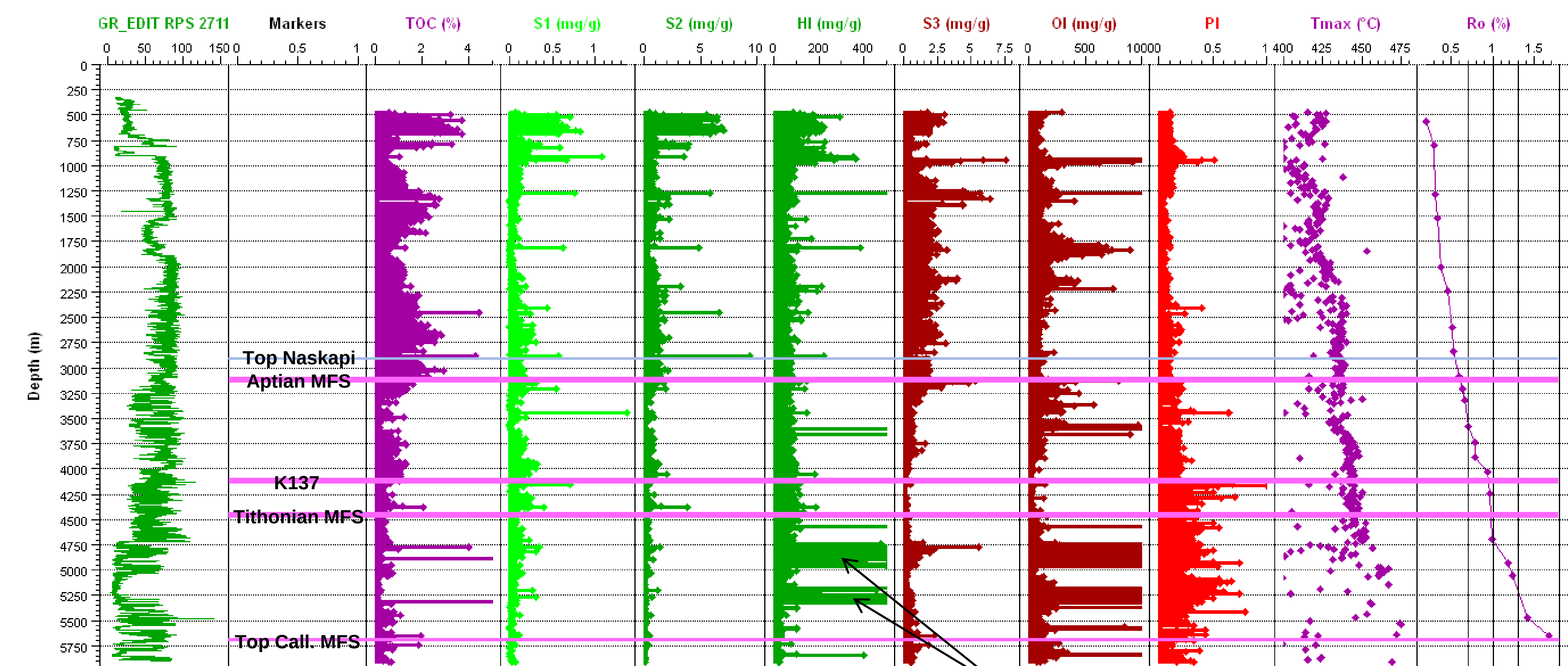


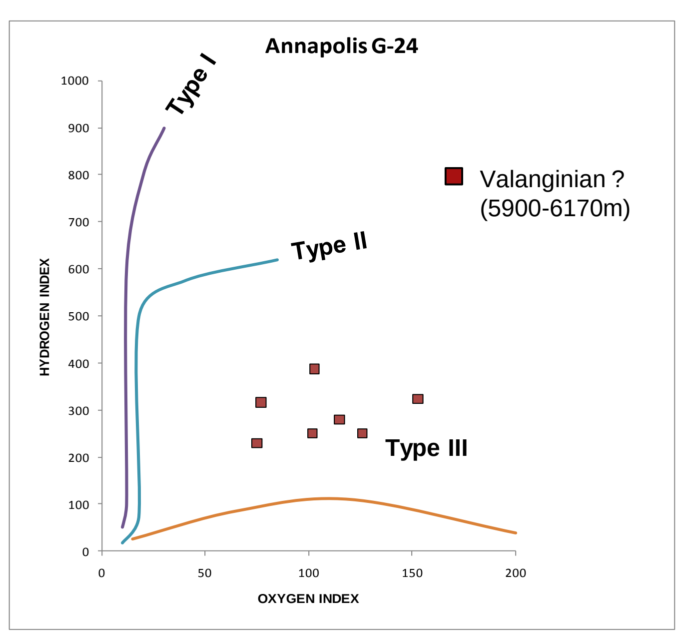
Top	Bottom	Units	Mud	Mud Additives	Event	Comments
5525	5525	M			FISH	MDT TOOL STUCK AT 5525 M - RECOVERED WITH OVERSHOT
5058	5058	M			KICK	3.0 M3 INFLUX WHILE CIRCULATING - MUD WEIGHT WAS MAINTAINED - INFLUX WAS CIRCULATED TO SURFACE
5508	5508	M				4.5 M3 KICK WHILE DRILLING - MUD WEIGHT INCREASED FROM 1582 TO 1654 KG/M3
5508	5508	M			LOST CIRC	77 M3 OF MUD WAS LOST WHEN MUD WEIGHT INCREASED TO 1726 KG/M3 AFTER KICK WAS CIRCULATED OUT
1714	2532	M	SEAWATER - PHG SWEEPS		MUD	
2532	6182	M	PARADRIL IA			SYNTHETIC OIL-BASED MUD
4450	4865	M			MUD MOTOR	INTERVAL DRILLED WITH DOWNHOLE MOTOR
4998	5058	M				

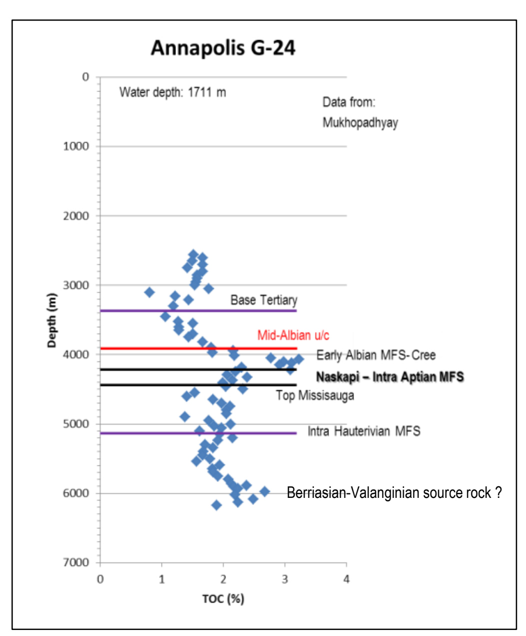
South Griffin J-13

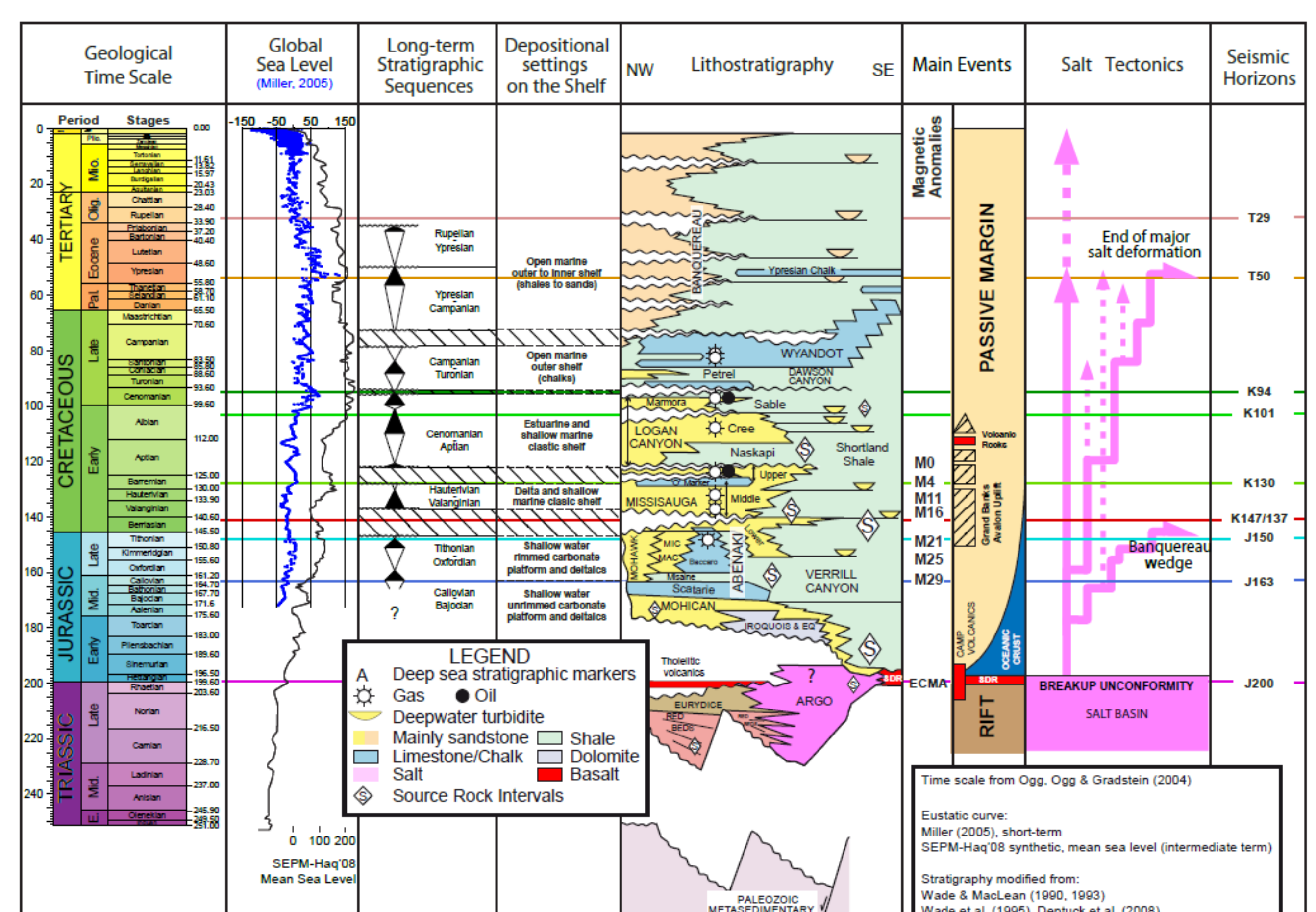


Top	Bottom	Units	Mud	Mud Additives	Event	Comments
924.5		M			FISH	DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
3115.4		M				
4027.7		M				TWO BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
4034.7		M				DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
4120		M				THREE BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
103	342.9	M	SEAWATER		MUD	
342.9	917.5	M	SEAWATER - XCD			
917.5	3115.1	M	SEAWATER - KCL POLYMER			
3115.1	5911.1	M	FRESHWATER - LIGNOSULFONATE	LIGNITE, LIGNOSULFONATE		
3215.9	3258.9	M			MUD MOTOR	TURBO DRILLED INTERVAL
3332.1	3450	M				
4178.5	4181.6	M				
4340	4356.2	M				

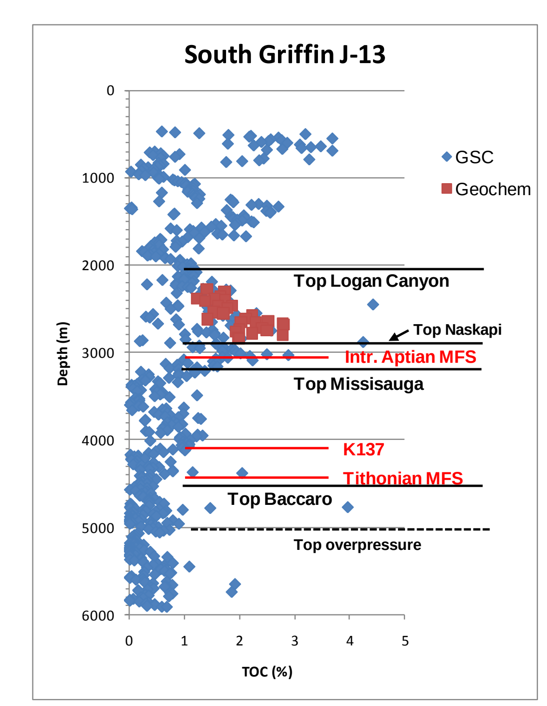


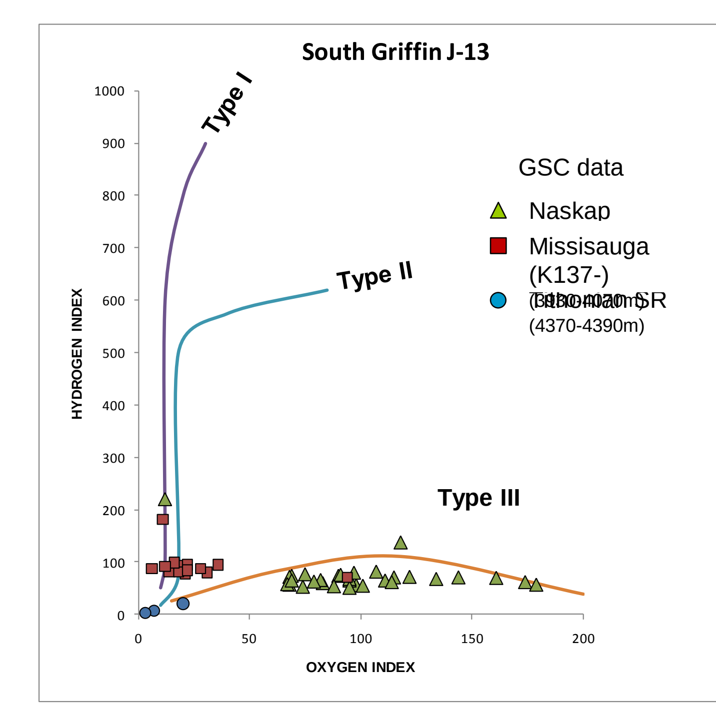






The large Hydrogen and Oxygen Indices below 3115m down to TD reflect contamination by mud additive (Lignosulfonate). Below the Tithonian MFS, HI values are too high for the elevate level maturity of that section of the well.

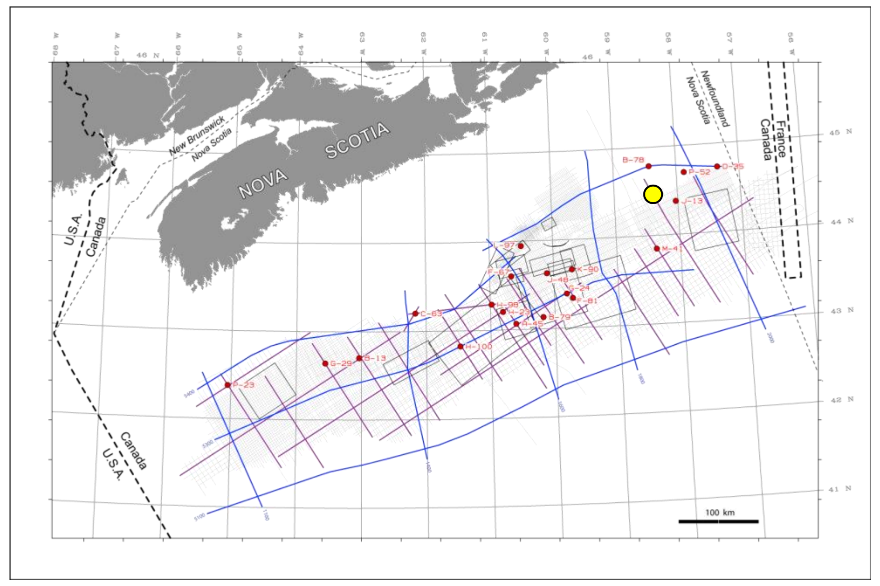




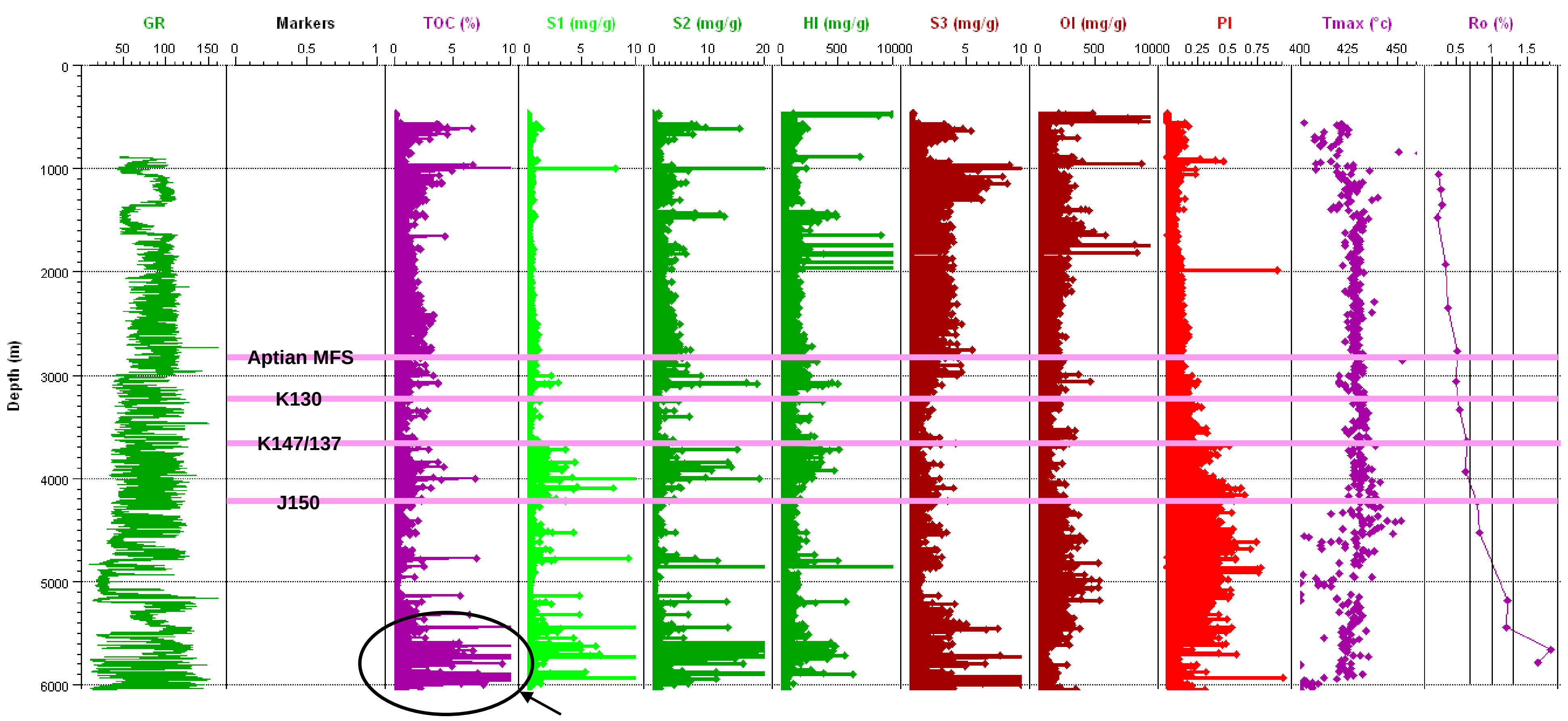
BASIC CHARACHTERISTICS:

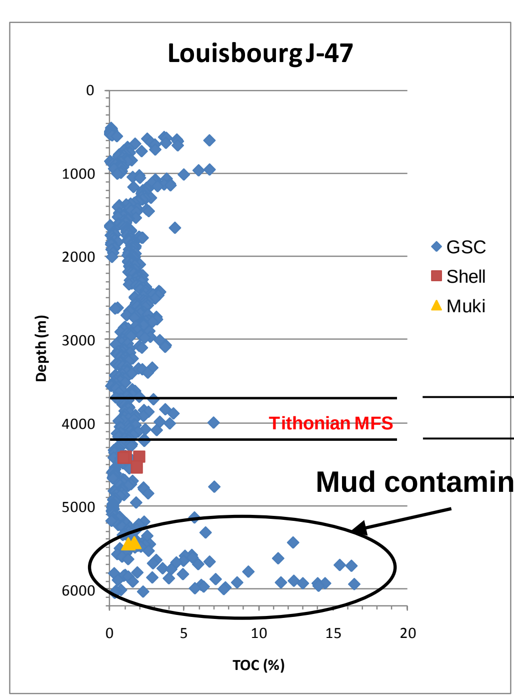
- TOC comprised between 1 and 2%
- Kerogen Type III
- The Berriasian/Valanginian source rock is considered minor but it honors the presence of the background source potential contained in the Missisauga that needs to be accounted for in Petroleum System modeling
- For modeling purpose, the following characteristics were retained:
  - TOC=2% (conservative)
  - Kerogen Type III

Louisbourg J-17

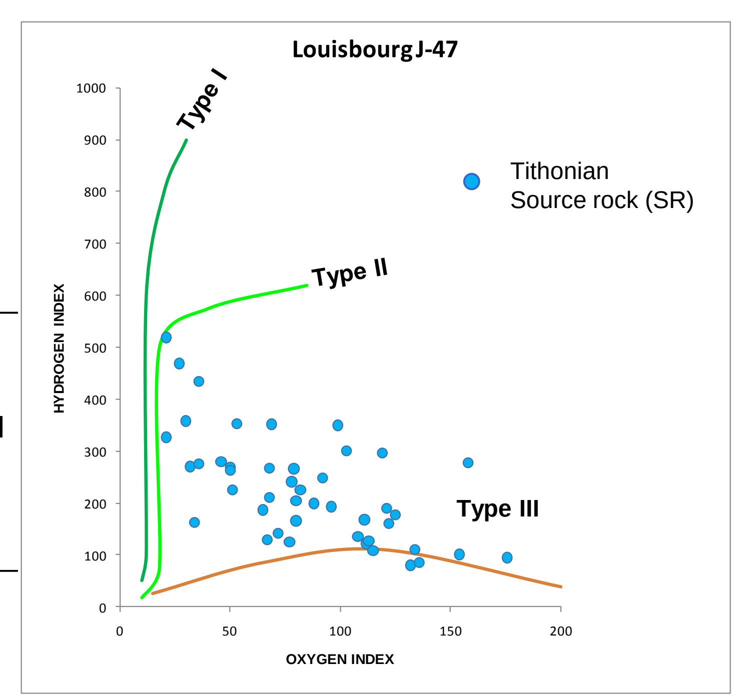


Top	Bottom	Units	Mud	Mud Additives	Event	Comments
370		M			FISH	660 MM HOLE OPENER STUCK - FISH RECOVERED
5386.5		M				DRILL COLLARS DROPPED IN HOLE - FISH RECOVERED
5475		M				BOTTOM HOLE TOOLS & TEST STRING STUCK IN HOLE AT 5475 M - TEST STRING RECOVERED - TOOLS LEFT IN HOLE
5838.5		M				LOGGING TOOL STUCK IN HOLE - FISH NOT RECOVERED
5840		M				PERFORATING ASSEMBLY STUCK IN HOLE AT 5752 - FISH PUSHED TO 5840 M WITH DRILL STRING - NOT RECOVERED
6511		M			KICK	INCREASED MUD WEIGHT BY 97 KG/M3 (FROM 2096 TO 2193 KG/M3)
101	262.4	M	SEAWATER - GEL-POLYMER SWEEPS		MUD	
262.4	898.2	M	GEL-POLYMER			
898.2	6042.4	M	KCL			
5455.1	5538.9	M			MUD MOTOR	TURBO DRILLED INTERVAL
5696.2	5738.5	M				
5847.4	5869.1	M				

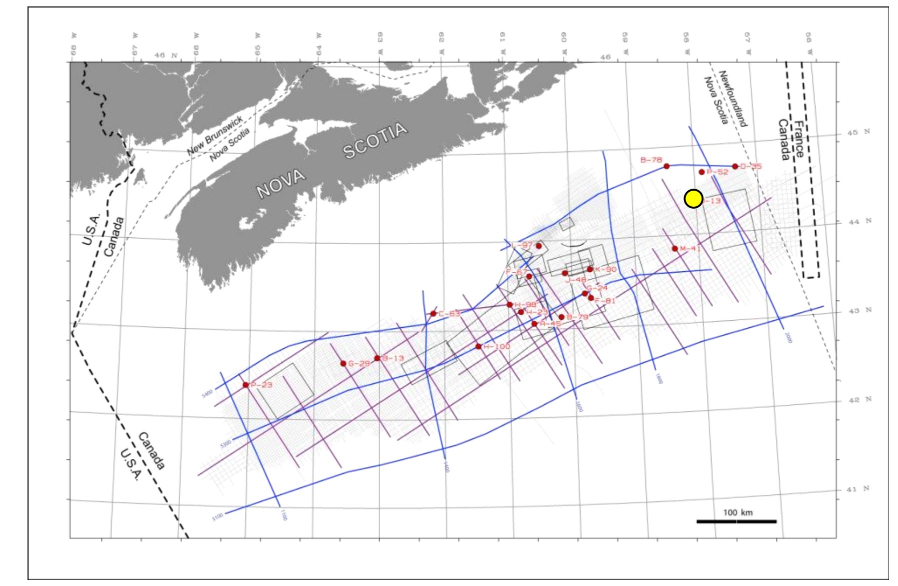




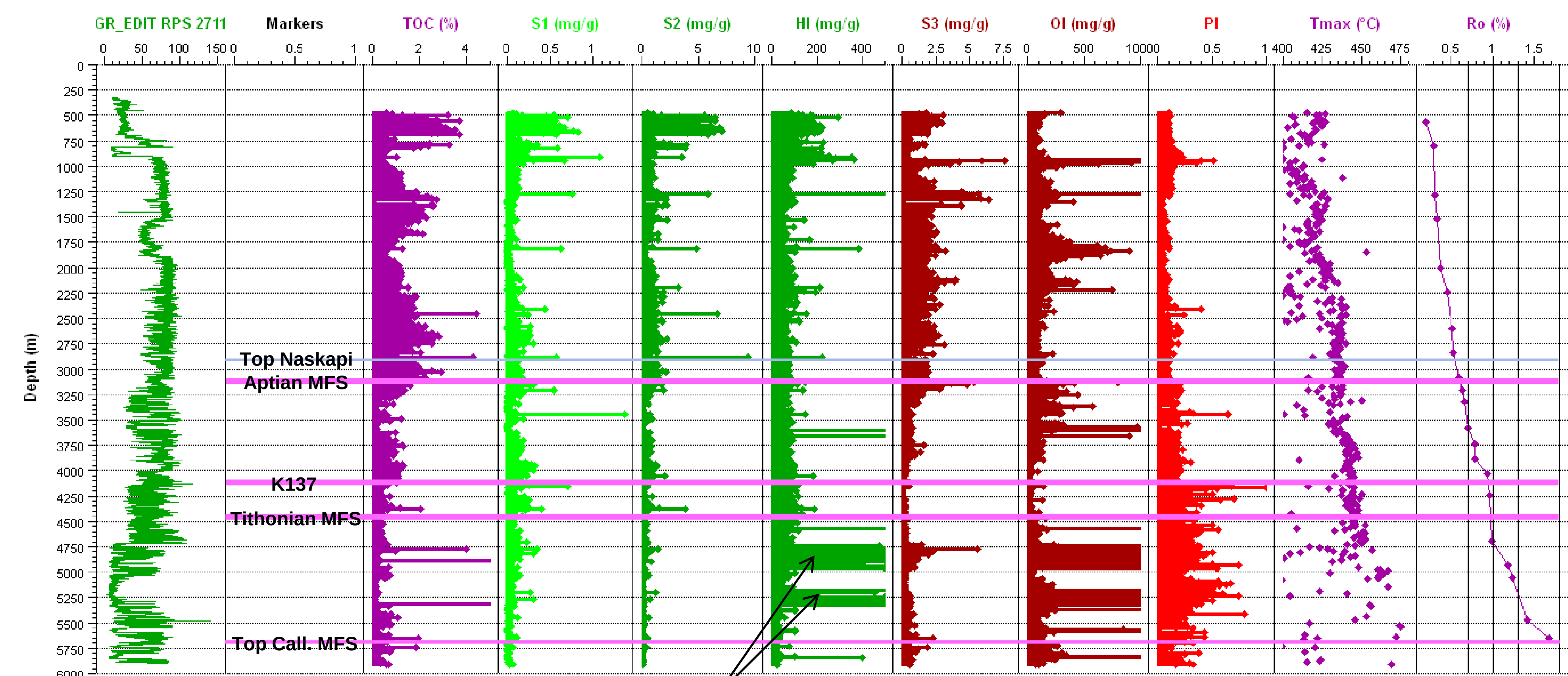
All data from the Tithonian MFS interval are plotted in the HIxOI diagram



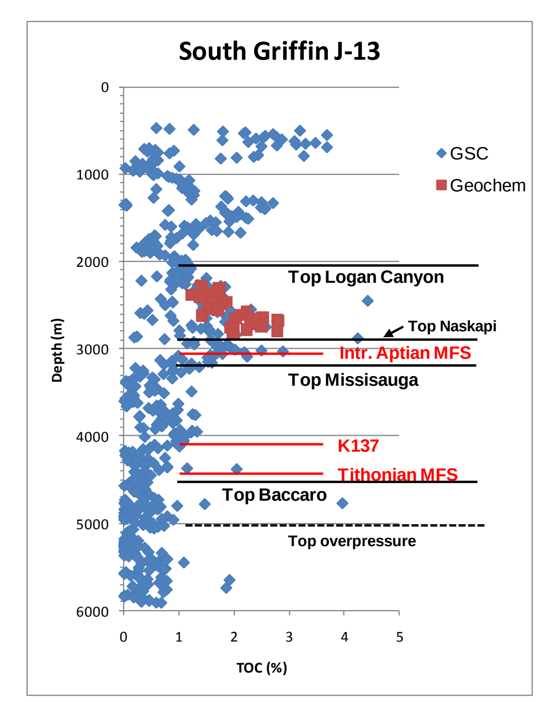
South Griffin J-13

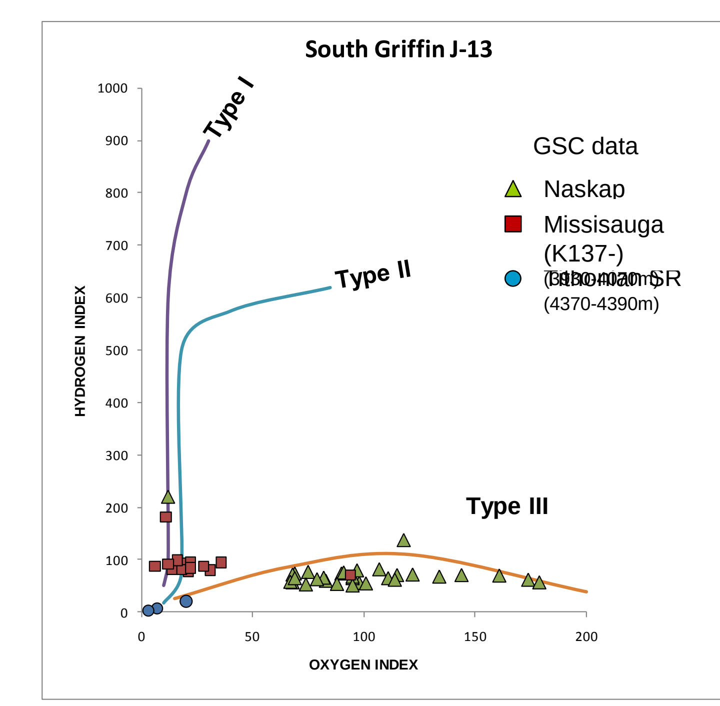


Top	Bottom	Units	Mud	Mud Additives	Event	Comments
924.5		M			FISH	DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
3115.4		M				
4027.7		M				TWO BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
4034.7		M				DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
4120		M				THREE BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
103	342.9	M	SEAWATER		MUD	
342.9	917.5	M	SEAWATER - XCD			
917.5	3115.1	M	SEAWATER - KCL POLYMER			
3115.1	5911.1	M	FRESHWATER - LIGNOSULFONATE	LIGNITE, LIGNOSULFONATE		
3215.9	3258.9	M			MUD MOTOR	TURBO DRILLED INTERVAL
3332.1	3450	M				
4178.5	4181.6	M				
4340	4356.2	M				



The large Hydrogen and Oxygen Indices below 3115m down to TD reflect contamination by mud additive (Lignosulfonate). Below the Tithonian MFS, HI values are too high for the elevate level maturity of that section of the well.





Organic facies in the interval J150 to K137 (Tithonian)

DEPTH (m)	TOC (%)	VR Ro (%)	OXIDATION LEVEL	ORGANIC INPUT	KEROGEN TYPE	OIL/GAS POTENTIAL
3995	3.36	0.7	mildly anoxic (shallow marine)	Terrestrial	IIB-III	Gas/Cond.
4005	1.71	0.7	mildly oxic (shallow marine)	Terrestrial	III	Gas

Organic facies in the interval TD to J150 (Mic Mac Oxfordian?)

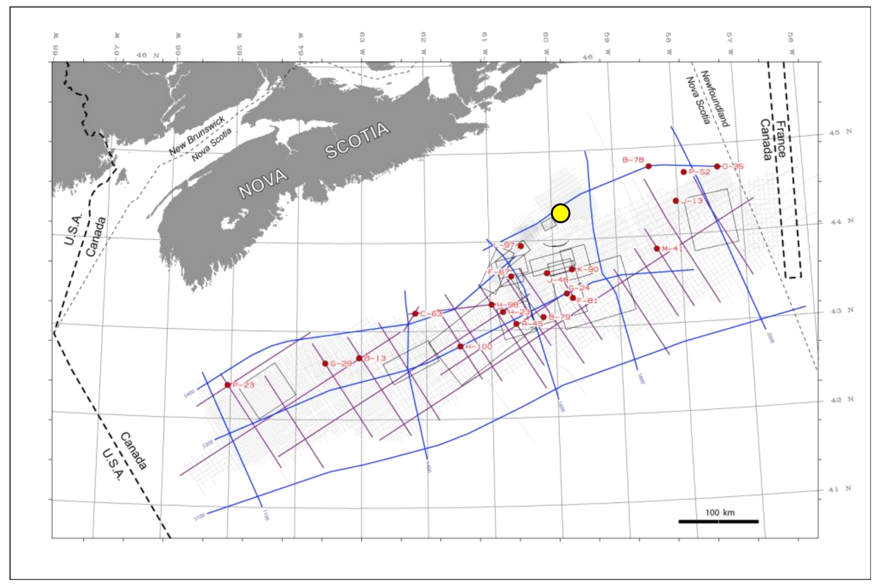
DEPTH (m)	TOC (%)	VR Ro (%)	OXIDATION LEVEL	ORGANIC INPUT	KEROGEN TYPE	OIL/GAS POTENTIAL
5455	2.15	~1.3	mildly anoxic (shallow marine)	Mixed	IIB	Cond./Oil/Gas
5580	0.49	~1.6	mildly anoxic (shallow marine)	Terrestrial	IIB	Gas/Cond.
5655	3.12	1.81	mildly anoxic (shallow marine)	Mixed	IIB	Cond./Gas

Reference:
P. K. Mukhopadhyay & Wade J. A. 1990. Organic facies and maturation of sediments from three Scotian Shelf wells. Bulletin of Canadian Petroleum Geology, Vol. 38, No. 4, pp. 407-425

The Tithonian source rock is well exemplified in Louisbourg J-47 and South Griffin J-13

- ✓ Maximum TOC reaches up to 7%, averaging 3% in Louisbourg J-47 at a
- ✓ Moderate level of maturity of Ro=0.7%
- ✓ Hydrogen and Oxygen Indices (HI & OI, respectively) indicate a mix Type II-III kerogen (see HI x OI diagram, left)
- ✓ In South Griffin J-13, the Tithonian source rock is deeper buried but quite more mature with HI x OI values showing a generative potential exhausted
- For modeling purpose, the following characteristics were retained:
  - TOC=5%
  - Kerogen Type II-III

Abenaki J-56

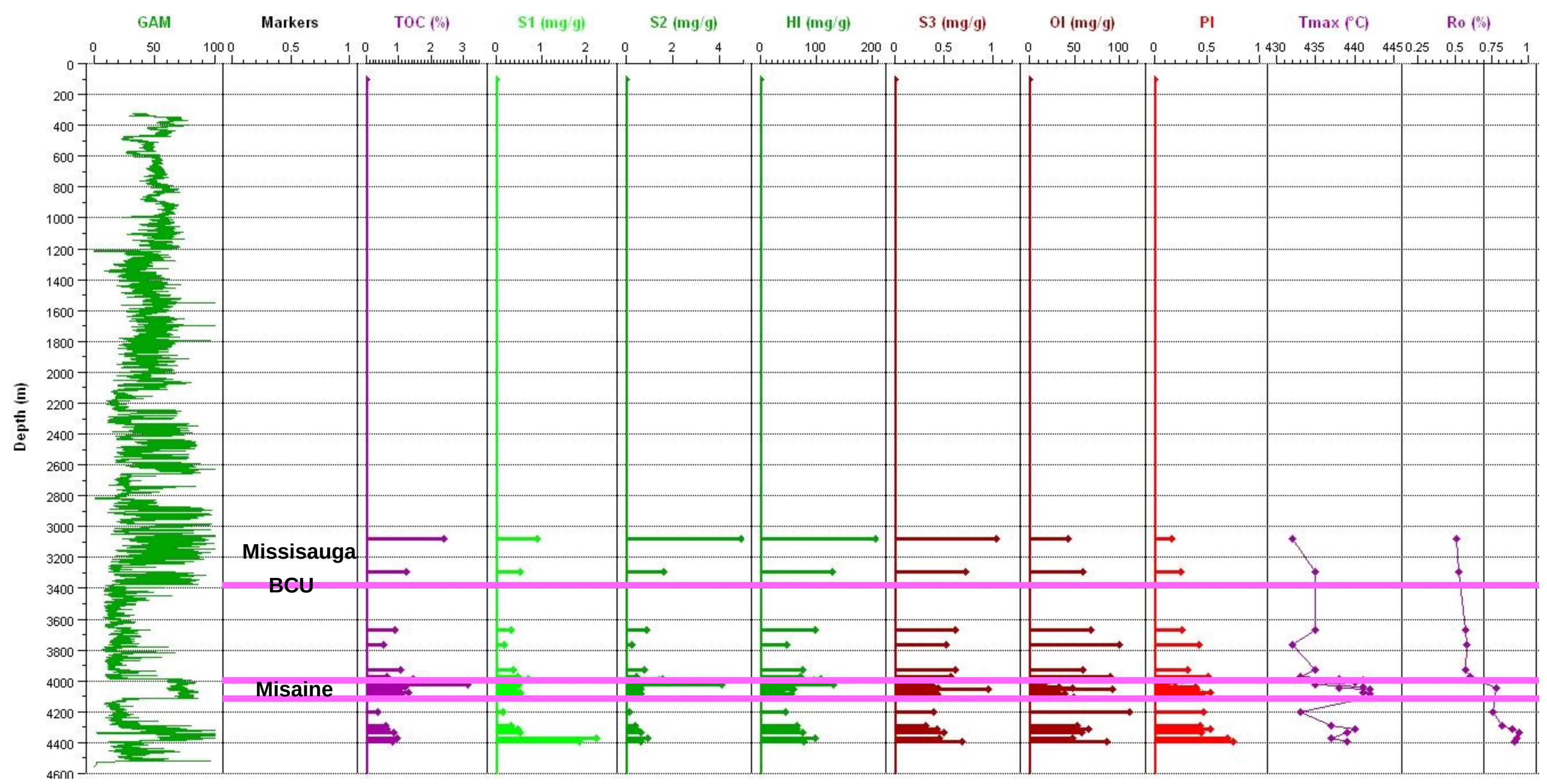


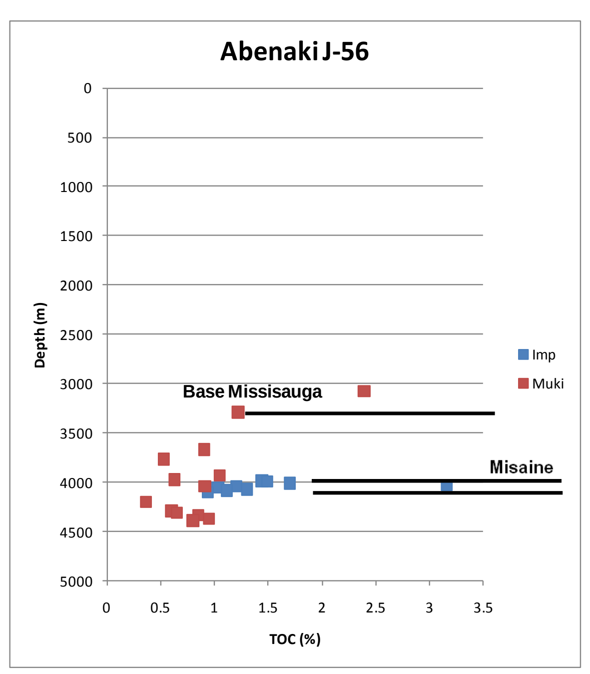
Top	Bottom	Units	Mud	Mud Additives	Event	Comments
8725	9300				LOST CIRC	LOST CIRCULATION MATERIAL ADDED: MICA, NUTPLUG & CELLOSEAL
435	1130	FT	TREATED GEL			
1130	14991		DLS	DIESEL (9312 & 14650 FT), SPERSENE, CROMEX, CELLOSEAL, NUTPLUG, PIPELAX	MUD	

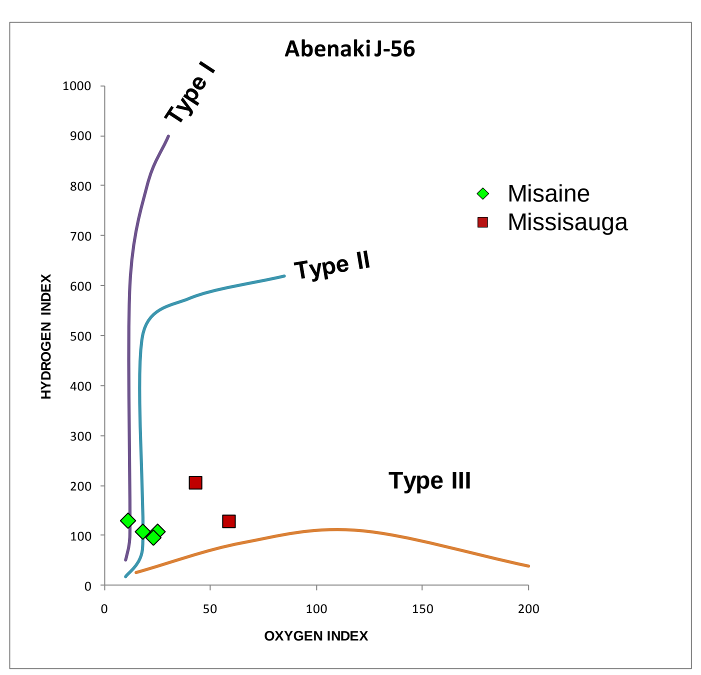
DLS = Dispersed Lignosulphonate

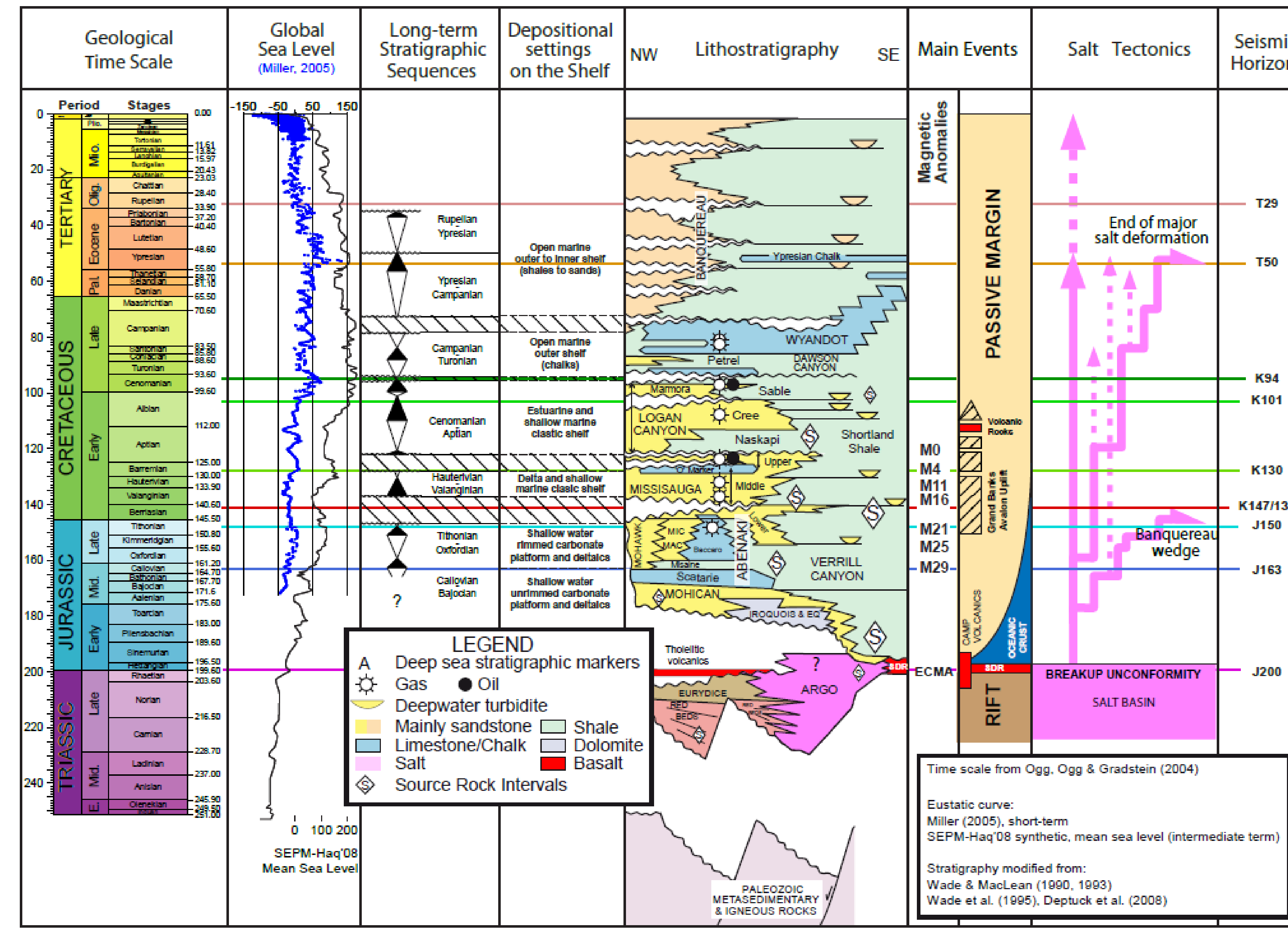
The Misaine source rock in Abenaki J-56

- ✓ Abenaki J-56 is contaminated by Dispersed Ligno-Sulfonate (DLS). However, low Rock Eval S1 peak (free hydrocarbons) suggest that the contamination is minimal if any
- ✓ HI x OI diagram indicates a Misaine source rock partly depleted in generative potential (HI=100), consistent with a level of maturity Tmax=441°C and a Ro=0.8% applied to a type II kerogen
- ✓ The Misaine source rock is honoring the fact that it corresponds to maximum flooding surfaces of the Callovian but it is considered minor as it is substantiated by only one well – Abenaki J-56
- ✓ For modeling purpose, the following characteristics were retained:
  - TOC=3%
  - Kerogen Type II-III







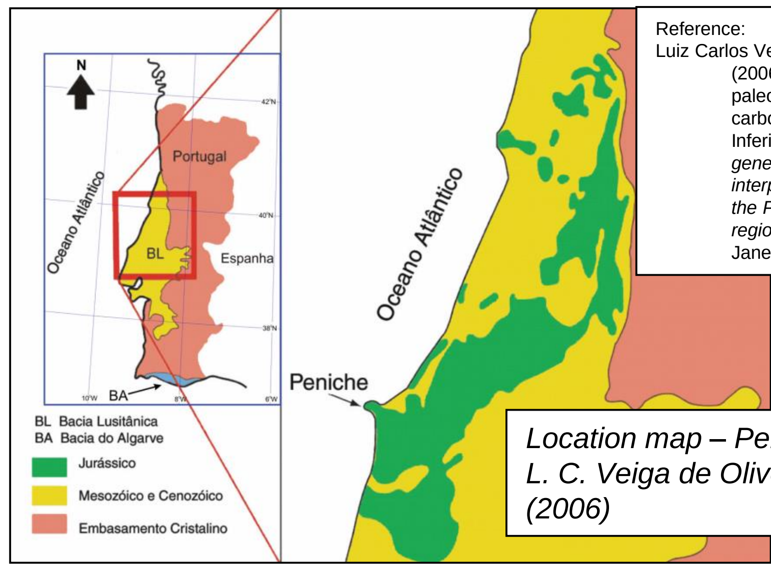


The Early Jurassic source complex

- ✓ Liassic sediments are missing in all wells drilled down to the Trias, except for Uniacke G-72, located down slope of the shelf edge prevailing at the time. Uniacke G-72 encountered remobilized Liassic clastics. Further out, Liassic sedimentation is expected to have taken place in the subsiding part of the basin.
- ✓ On the Portugal side of the opening proto-Atlantic ocean, Sinemurian, Pliensbachian and Toarcian source rocks are known to exist. There is therefore et strong possibility that their equivalent be present on the Nova Scotia margin.
- ✓ On the Morocco margin, Toarcian source rocks are proven.

In Portugal

Luiz Carlos Veiga de Oliveira et al. (2006) publication reports the following :



Reference:
Luiz Carlos Veiga de Oliveira, Rodrigues R., Duarte L. V. Lemos V. B. (2006). Avaliação do potencial gerador de petróleo e interpretação paleoambiental com base em biomarcadores e isótopos estáveis de carbono da seção Pliensbaquiano - Toarciano inferior (Jurássico Inferior) da região de Peniche (Bacia Lusitânica, Portugal). *Oil generation potential assessment and paleoenvironmental interpretation based on biomarkers and stable carbon isotopes of the Pliensbachian - Lower Toarcian (Lower Jurassic) of the Peniche region (Lusitanian Basin, Portugal).* B. Geoci. Petrobras, Rio de Janeiro, v. 14, n. 2, p. 207-234, maio/nov. 2006

Location map – Peniche Basin L. C. Veiga de Oliveira et al. (2006)

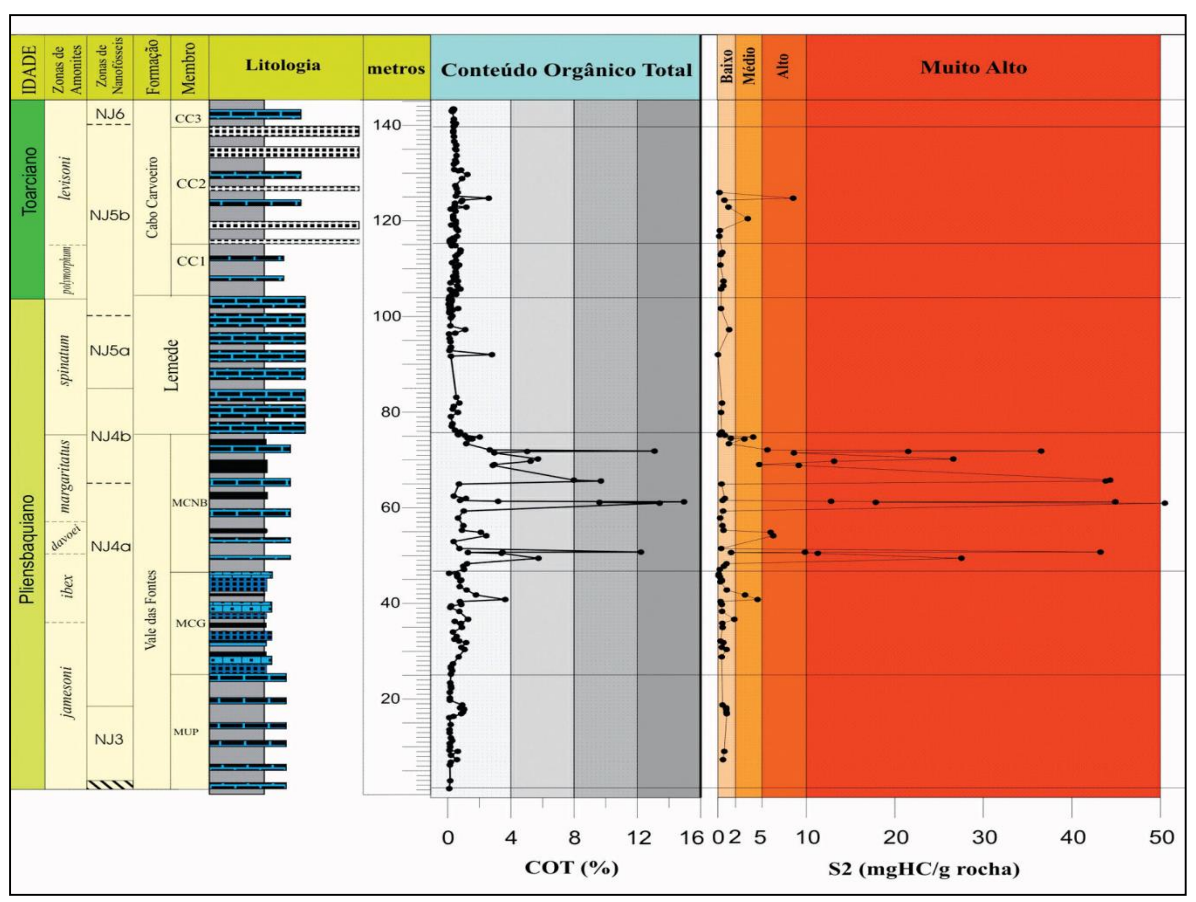
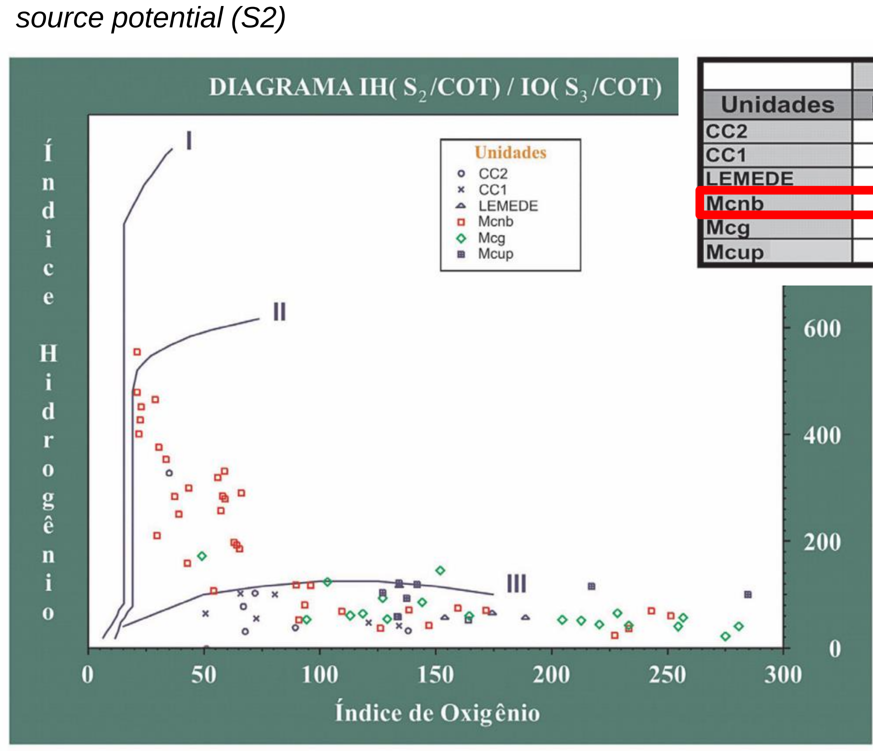


Figure 1: Stratigraphy, Lithology and Rock Eval Total Organic Carbon content (TOC) & source potential (S2)



	IH		IO	
Unidades	Média	Máx.	Média	Máx.
CC2	101,28	327,69	78,22	138,09
CC1	68,16	101,56	87,46	134,24
LEMEDE	58,58	116,22	176,15	354,45
Mcnb	210,16	555,26	89,04	251,39
Mcg	67,17	172,63	185,3	344,26
Mcup	101,55	121,52	168,04	284,74

Figure 2: Diagram of Hydrogen Index x Oxygen index (HI x OI) for samples of Peniche Basin

Peniche Basin (Luiz Carlos Veiga de Oliveira et al., 2006)

- ✓ The Mncb Member (MLOF* Mbr. in L. V. Duarte, 2010; see Figure 3 on the right) of the Vale das Fontes Formation of Pliensbachian age is definitely an organic-rich source rock with TOC up to in excess of 14%, averaging 3.8% over the Mncb interval 28m thick (see Figure 2).
- ✓ An bitumen extract from the sample at 72.12m analyzed by Gas Chromatography – Mass Spectrometry (Figure 4) displays a large Gammacerane peak on the m/z 191 trace shown below. It compares closely with the trace of a condensate from DST#6 of the Venture B-13 discovery well offshore Nova Scotia also shown in Figure 4 below.

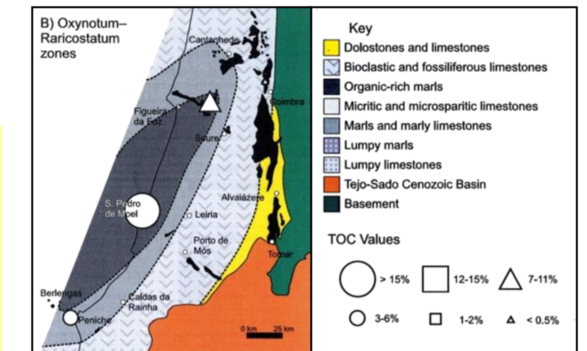
* MLOF = Marly Limestones with Organic-rich Facies

Lusitanian Basin (L. V. Duarte, 2010)

- ✓ In addition to the Pliensbachian source rock, Duarte et al. (2010) reports a very rich source rocks of Sinemurian age in San Pedro de Moel area (see location map & Figure 3) exhibiting maximum TOC in excess of 20% for two samples, otherwise of richness comparable to the Pliensbachian described by Luiz Carlos Veiga de Oliveira et al. (2006) over a similar thickness.

L.V. Duarte et al. (2006) publication reports the following :

Reference:
L.V. Duarte, R.L. Silva, L.C.V. Oliveira, M.J. Comas-Rengifo, F. Silva (2010). Organic-Rich Facies in the Sinemurian and Pliensbachian of the Lusitanian Basin, Portugal: Total organic carbon distribution and relation to transgressive-regressive facies cycles . Geologica Acta, Vol. 8, No. 3, pp. 325-340.



Location map and TOC distribution in the Sinemurian of the Lusitanian Basin (L. V. Duarte, 2010)

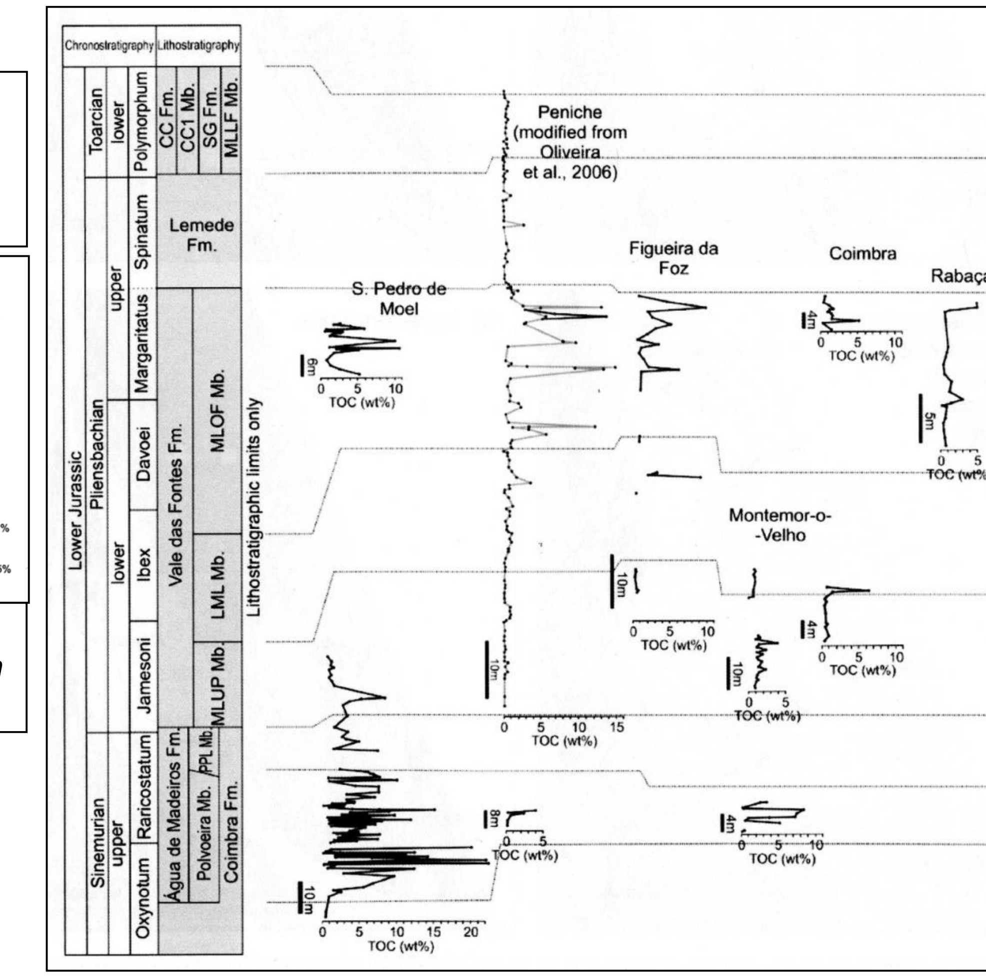


Figure 3: TOC distribution in the uppermost Sinemurian-Pliensbachian of the Lusitanian Basin (L. V. Duarte, 2010)

Gammacerane in Venture B-13 DST#6 condensate

- ✓ Gammacerane found in the Venture B-13 condensate of DST# 6 sample compared to the extract from an organic-rich Pliensbachian sample (see Figure 4 below) strengthen the simple analogy with the Peniche Basin, providing a direct argument in favor of the presence of potential Liassic source rock on the Nova Scotia margin
- ✓ Of course, due to largely generalized use of mud additive during drilling operations on the Nova Scotia margin, contamination in the Venture B-13 well needed to be checked
- ✓ In normal circumstances DSTs should not be affected by mud contaminants. However, if the reservoir tested was invaded by mud fluids prior to testing, it may give back contaminant in the test

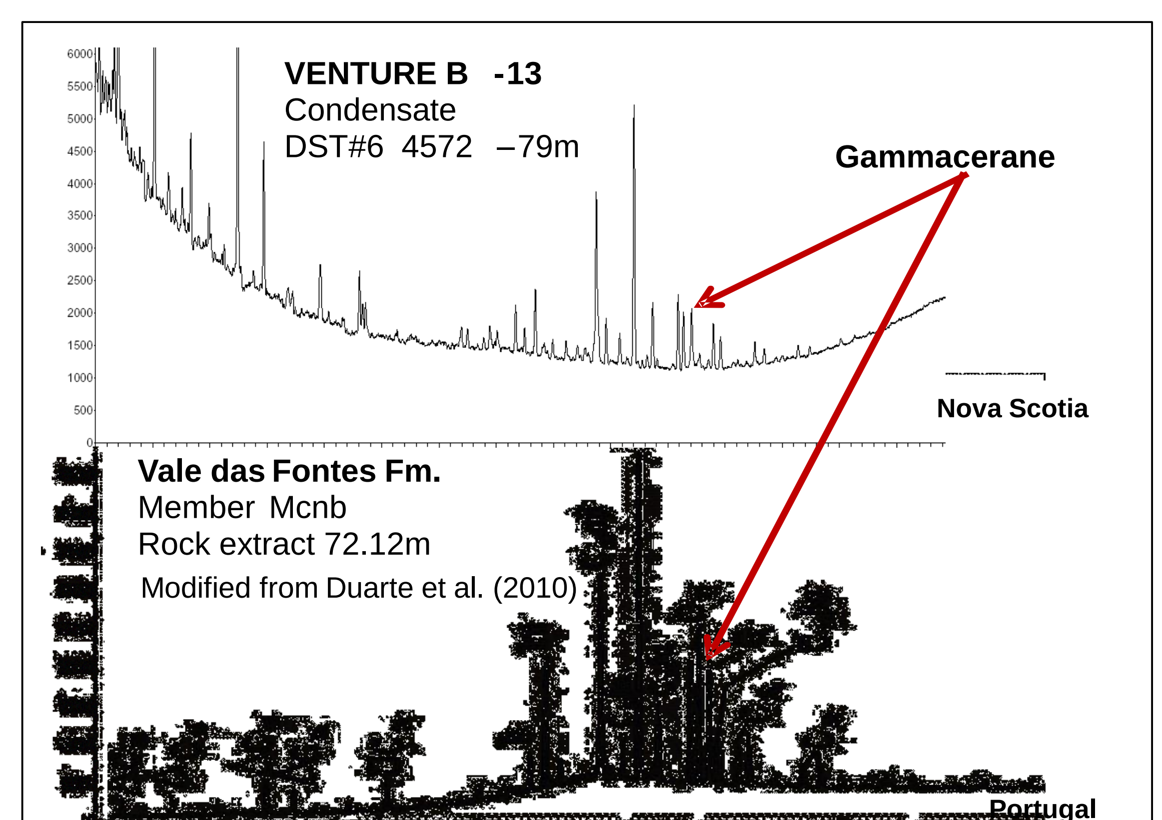


Figure 4:Biomarker traces (m/z 191). Gammacerane is present in the condensate of Venture B-13 DST#6 and in an extract from the Mncb Member of the Pliensbachian Vale das Fontes Formation

Gammacerane – contaminant or indigenous?

- ✓ Cutting extracts were analyzed for Gammacerane based on the principle that cuttings would be most affected by a gilsonite type of mud additive containing Gammacerane.
- ✓ Results shown in Figure 5 are that Gammacerane in the 4570m cuttings, just above the tested interval is not anomalously abundant, whereas it is in the 4580m cutting below DST#6
- ✓ This distribution of Gammacerane in the cuttings tends to demonstrate that Gammacerane in DST#6 condensate is not contamination by mud additive

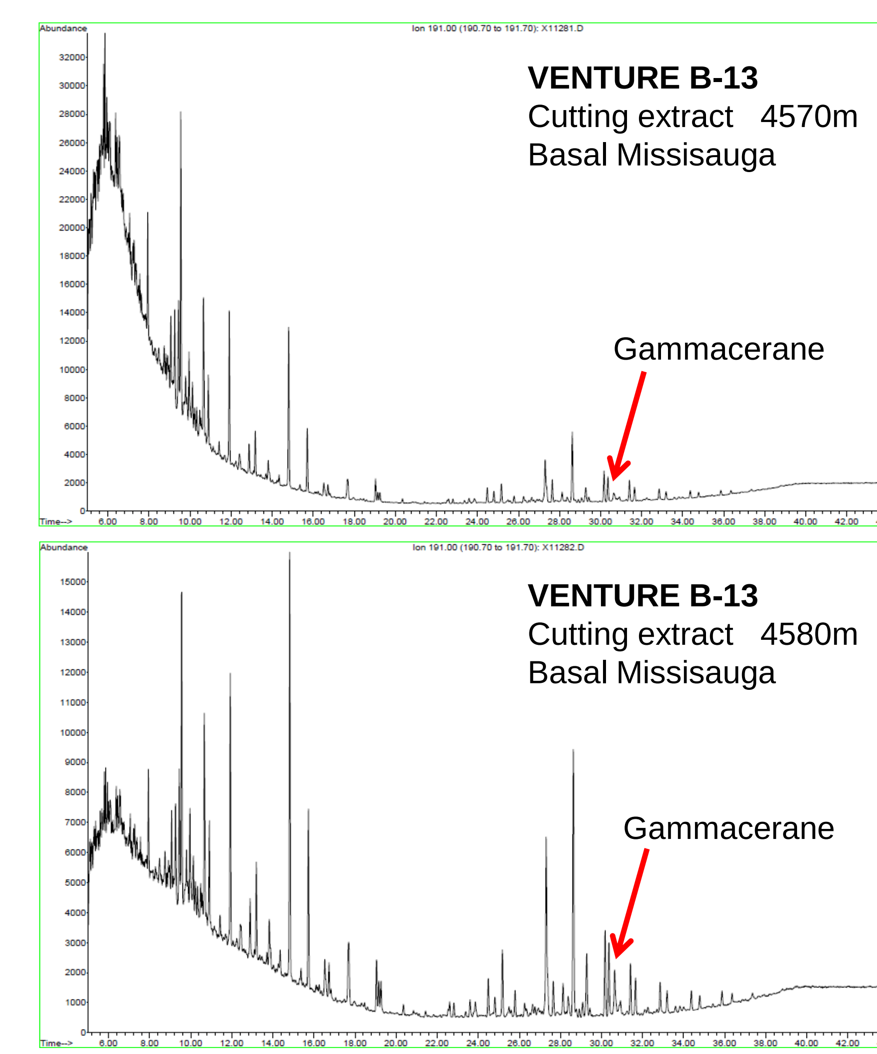
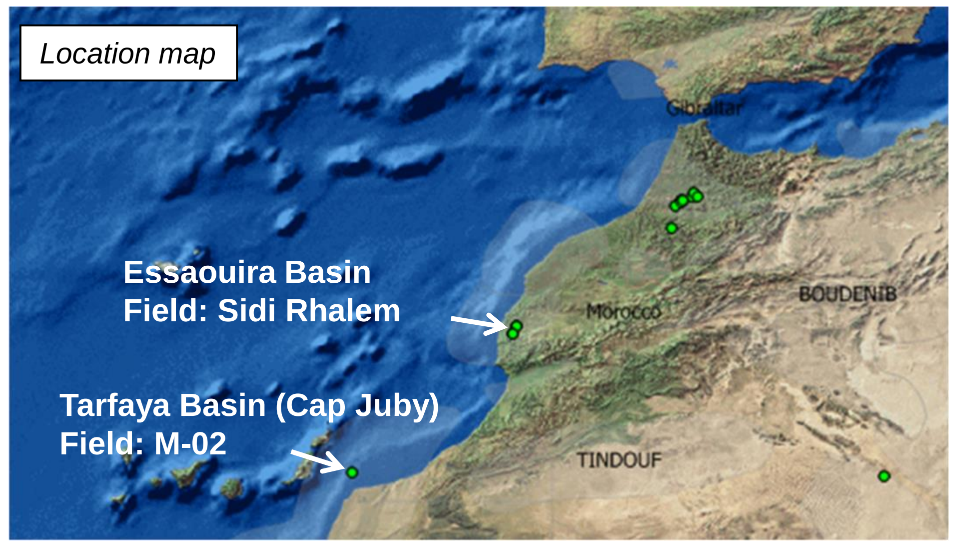


Figure 5: Biomarker traces (m/z 191) of cutting extracts from Venture B-13. Gammacerane is not anomalously abundant at the depth just above DST#6 (4570m) but well developed at 4580 m, just below the tested interval

In Morocco

Based on data graciously provided by Geomark Research Inc.:



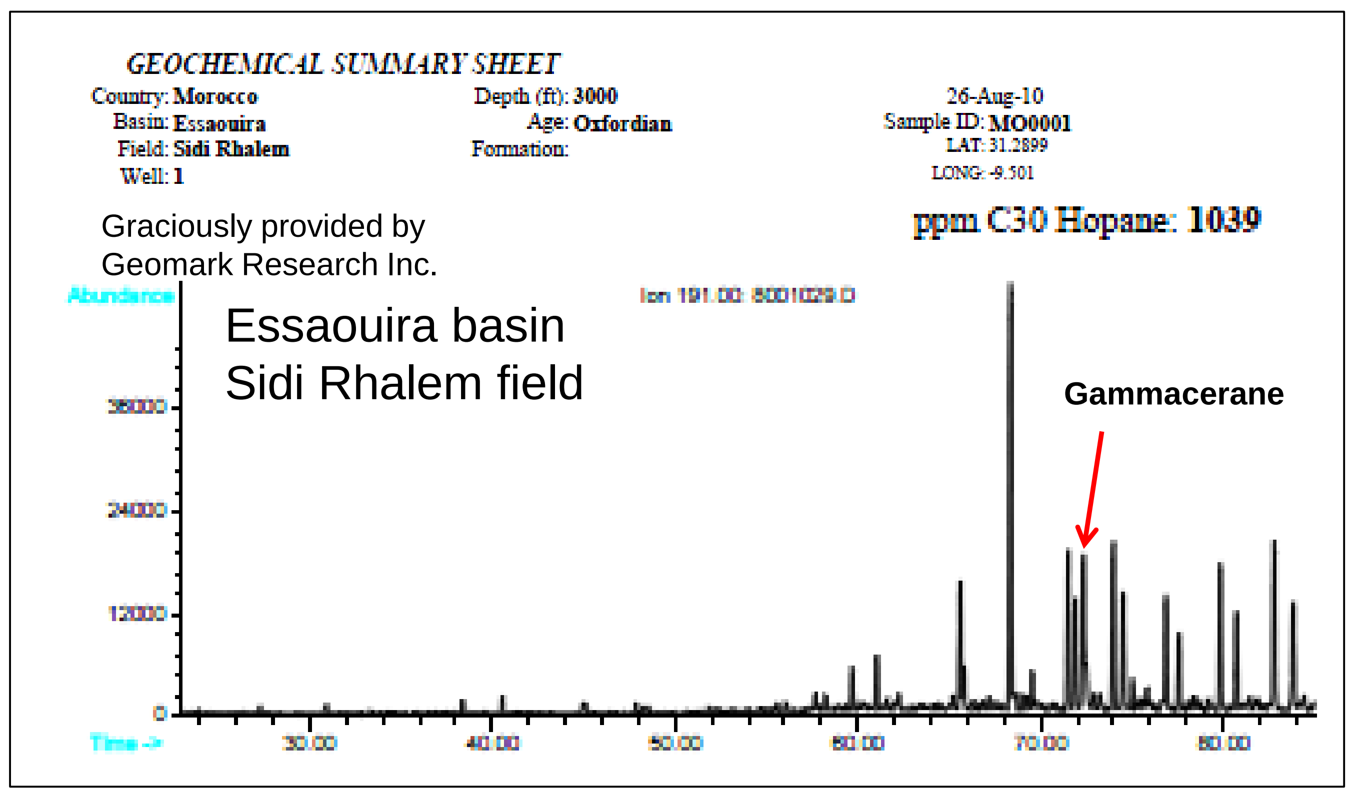


Figure 1: Biomarker traces (m/z 191). Gammacerane is present in the oil of the Sidi Rhalem field, Essaouira Basin, Morocco

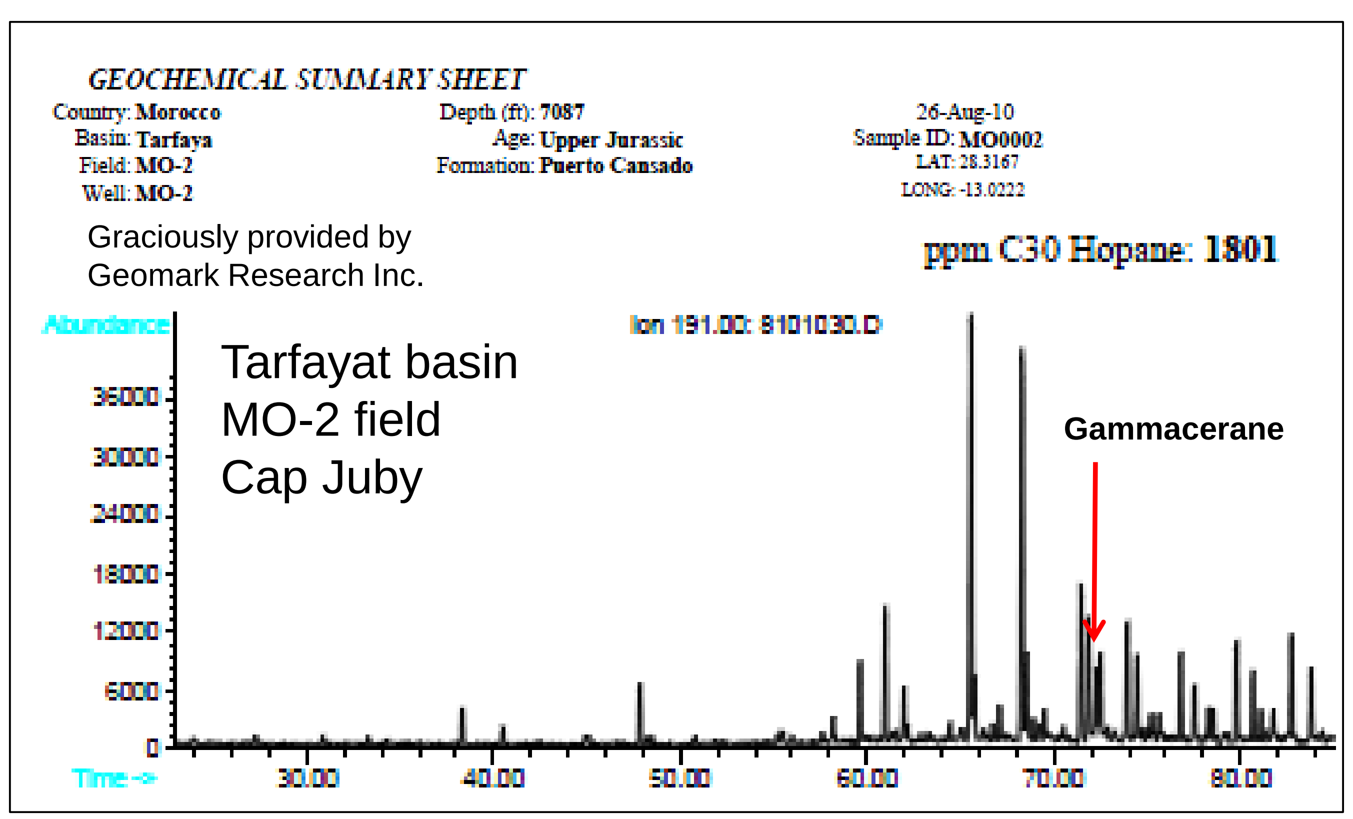


Figure 2: Biomarker traces (m/z 191). Gammacerane is present in the oil of the MO-2 field, Tarfayat Basin, Cap Juby, offshore Morocco

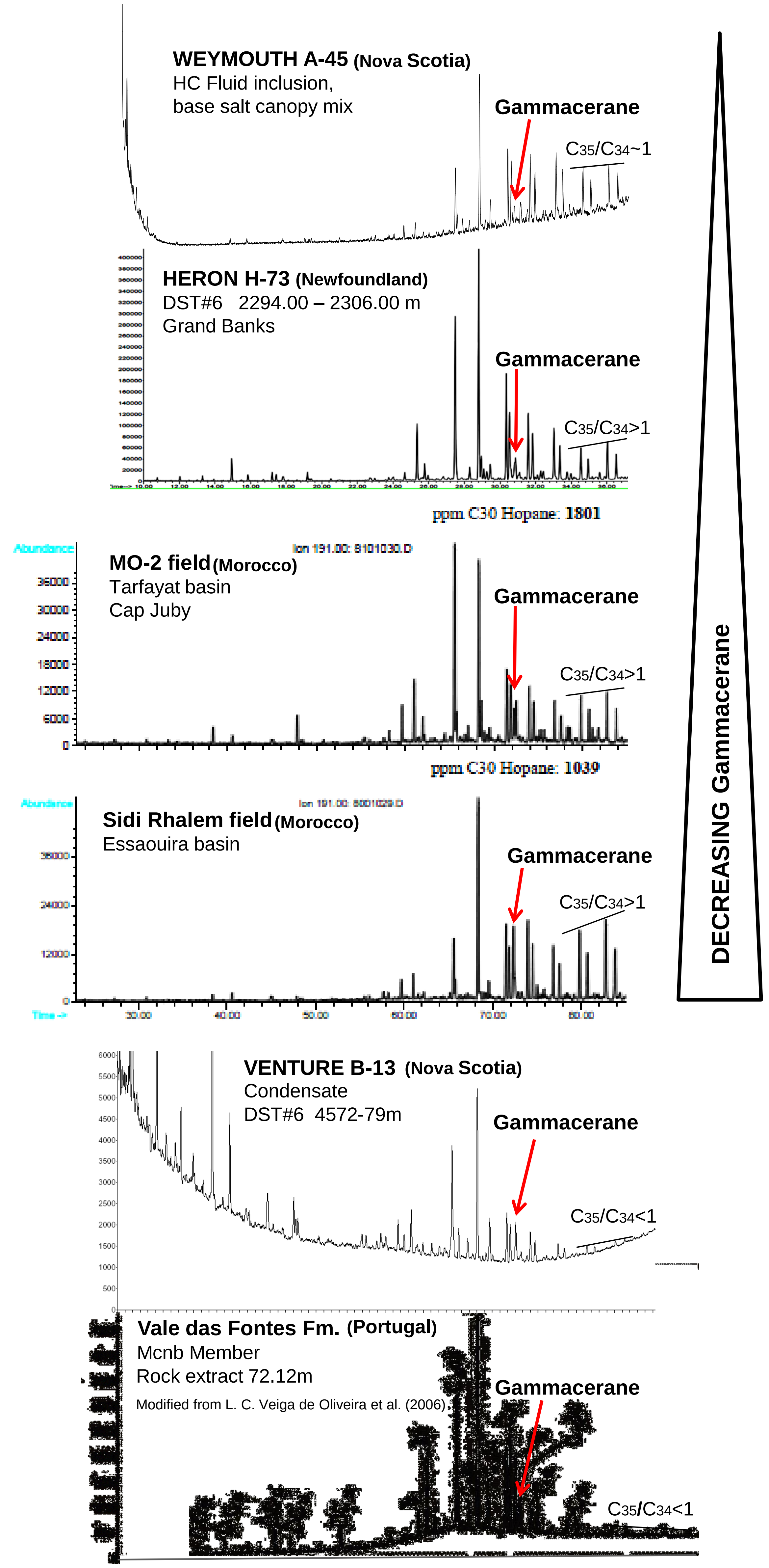


Figure 3: Biomarker traces (m/z 191) of various oils, condensate, extracts and HC fluid inclusion all exhibiting Gammacerane and a homohopane C_{35}/C_{34} ratio. A low C_{35}/C_{34} ratio <1 is commonly associated with marine carbonates and evaporites. It is at least a general indicator of highly reducing marine conditions during deposition (Peters and Moldowan, 1991)

Gammacerane & depositional environments

- ✓ Gammacerane forms by reduction of tetrahymanol. The source of tetrahymanol appears to be bacterivorous ciliates, which occur at the interface between oxic and anoxic zones of stratified water columns.
- ✓ Abundant Gammacerane is believed to indicate the presence of stratified water column.
- ✓ Although stratified water column can result from both hypersalinity at depth (halocline) and temperature (thermocline), high abundance of Gammacerane is mostly found in high salinity environments and evaporites.
- ✓ The most likely environments for a source of Gammacerane on the Nova Scotia margin would be:
  - Early Jurassic (Liassic), post-rift with high salinity at the end of the Argo salt deposition changing progressively to carbonate and more open marine environments, or
  - Triassic.

Homopane C35/C34 ratio & depositional environments

- ✓ High C_{35}-homopane compared to C_{34}-homohopane (see Figure 3) is commonly associated with marine carbonates and evaporites. It is at least a general indicator of highly reducing marine conditions during deposition (Peters and Moldowan, 1991) providing a highly favorable environment for source rock deposition and preservation.

Gammacerane & Homopane C35/C34 ratio

- ✓ C_{35}/C_{34} homohopane ratios in oils and Gammacerane abundance in oils, condensates and fluid inclusion oil presented here (Figure 3) do not show a direct relationship. The source rock portion of the Pliensbachian Vale das Fontes Formation of Portugal displays Gammacerane but the C_{35}/C_{34} homohopane ratio does not exhibit any sign of highly reducing conditions, yet it is associated to an organic-rich source rock well preserved, the facies of which is marly rather than pure carbonates (Duarte et al., 2010).
- ✓ Taking Gammacerane and the C_{35}/C_{34} homohopane ratio as indicators of salinity and, reducing and/or carbonate deposition conditions, respectively, supports the environments foreseen for the Early Jurassic source rock complex based on the Moroccan and Portuguese margins.
- ✓ In addition, organic-rich Toarcian offshore Morocco, DSDP Leg 79 Site 547, consist of black shale is associated to a carbonate environment of deposition without any sign of hypersalinity. Accordingly, the hopane trace (ion 191) of extracts from several black shale samples collected and analyzed for this study display very lean Gammacerane content only, nothing more than a usual background (see below Figure 4).

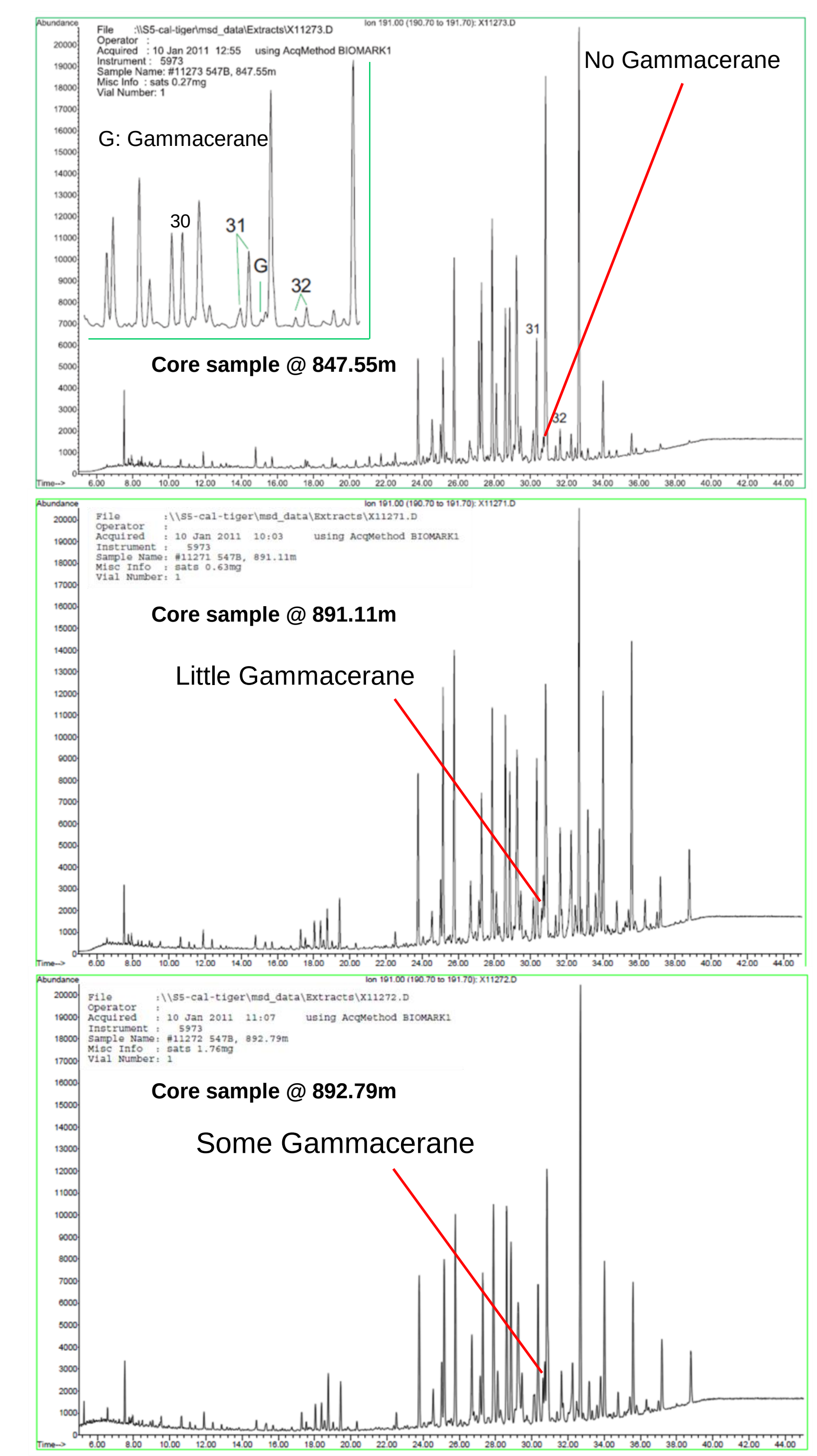


Figure 4: Ion 191 traces of three samples of Toarcian black shales from DSDP Leg 79 Site 547, well 547B. These traces display no or background abundance of Gammacerane. The shallow depth of these samples explains their immaturity and unusual signature. Location, analytical results and geological context are discussed in the next Plate

In Morocco (continued)

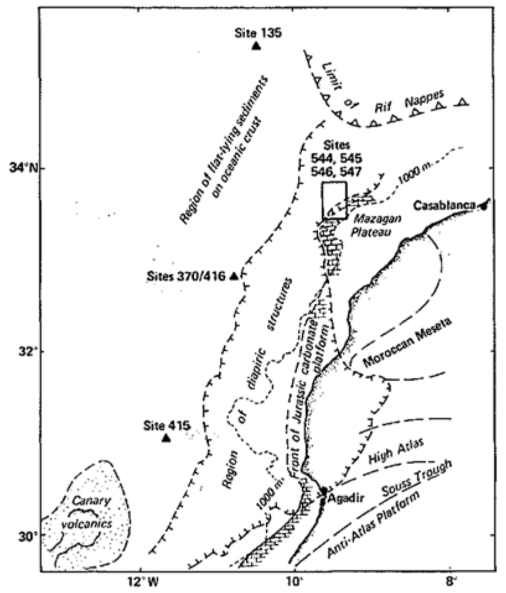


Figure 1: Location of DSDP drill sites Leg 79, Site 547 (within rectangle) on the Morocco margin (modified from Rullkotter et al. 1984).

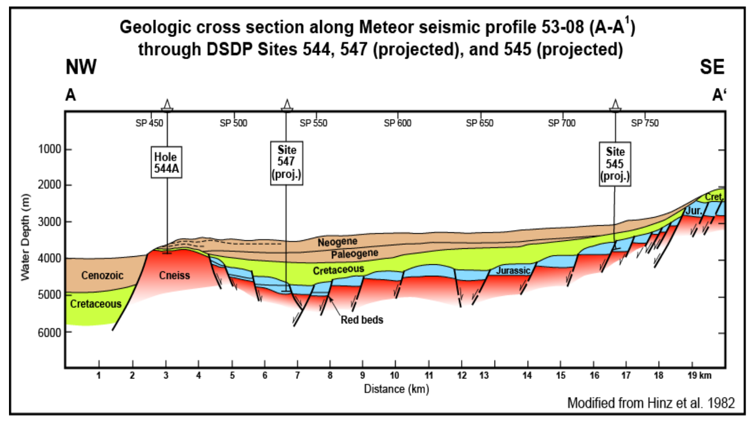


Figure 2: Cross section showing well locations of DSDP Leg 79, Sites 544, 545 and 547

EXPEDITION (Leg)	SITE	HOLE	CORE	SECTION	SAMPLE	LOCATION	SECTION_ID	TOP_DEPTH	BOTTOM_DEPTH	ANALYST	REQUEST	EQUEST_PAR	TYPE	VOLUME	SAMPLE_DATE	REMARKS	HALF	MBSF_TOP	MCD_TOP
79	547	B	15	2	4421954	BCR	970576	5	9	WH	22219	A	---	5	11/25/2010 10:35:56 AM		W	847.55	847.55
79	547	B	20	1	4421955	BCR	970671	11	18	WH	22219	A	---	5	11/25/2010 10:40:45 AM		W	891.11	891.11
79	547	B	20	1	4421956	BCR	970671	130	133	WH	22219	A	---	7	11/25/2010 10:48:27 AM		W	892.3	892.3
79	547	B	20	2	4421957	BCR	970666	29	32	WH	22219	A	---	8	11/25/2010 10:51:49 AM		W	892.79	892.79
79	547	B	20	2	4421958	BCR	970666	51	66	WH	22219	A	---	7	11/25/2010 10:55:23 AM		W	893.01	893.01
79	547	B	20	2	4421959	BCR	970666	89	96	WH	22219	A	---	10	11/25/2010 10:57:46 AM		W	893.39	893.39
79	547	B	22	1	4421960	BCR	970706	20	30	WH	22219	A	---	10	11/25/2010 11:00:59 AM		W	905.2	905.2

Table 1: List of the core samples collected from DSDP well 547B for analyses.

Depth	Sample	Qty	Tmax	S1	S2	S3	PI	S2/S3	PC(%)	TOC(%)	HI	OI
0	9107	70.7	442	0.74	12.21	0.55	0.06	22.20	1.11	5.05	242	11
847.55	4421954	70.0	423	0.10	4.04	2.87	0.02	1.41	0.47	2.70	150	106
891.11	4421955	70.9	423	0.13	8.82	1.94	0.01	4.55	0.82	2.38	371	82
892.3	4421956	70.3	423	0.03	0.25	1.56	0.10	0.16	0.08	0.59	42	264
892.79	4421957	70.6	425	0.10	6.31	1.71	0.02	3.69	0.61	2.92	216	59
893.01	4421958	70.1	425	0.04	0.63	1.80	0.05	0.35	0.12	0.87	72	207
893.39	4421959	70.3	491	0.00	0.01	1.78	0.21	0.01	0.07	1.16	1	153
905.2	4421960	70.6	425	0.05	0.53	1.61	0.08	0.33	0.11	0.93	57	173
0	9107	70.4	442	0.72	12.18	0.63	0.06	19.33	1.11	5.09	239	12

Table 2: TOC/Rock Eval data acquired on the cores samples collected from DSDP well 547B. (Yellow outline: TOC/Rock Eval standard; Red outline: source rock samples (see Biomarker traces in Figure 6)

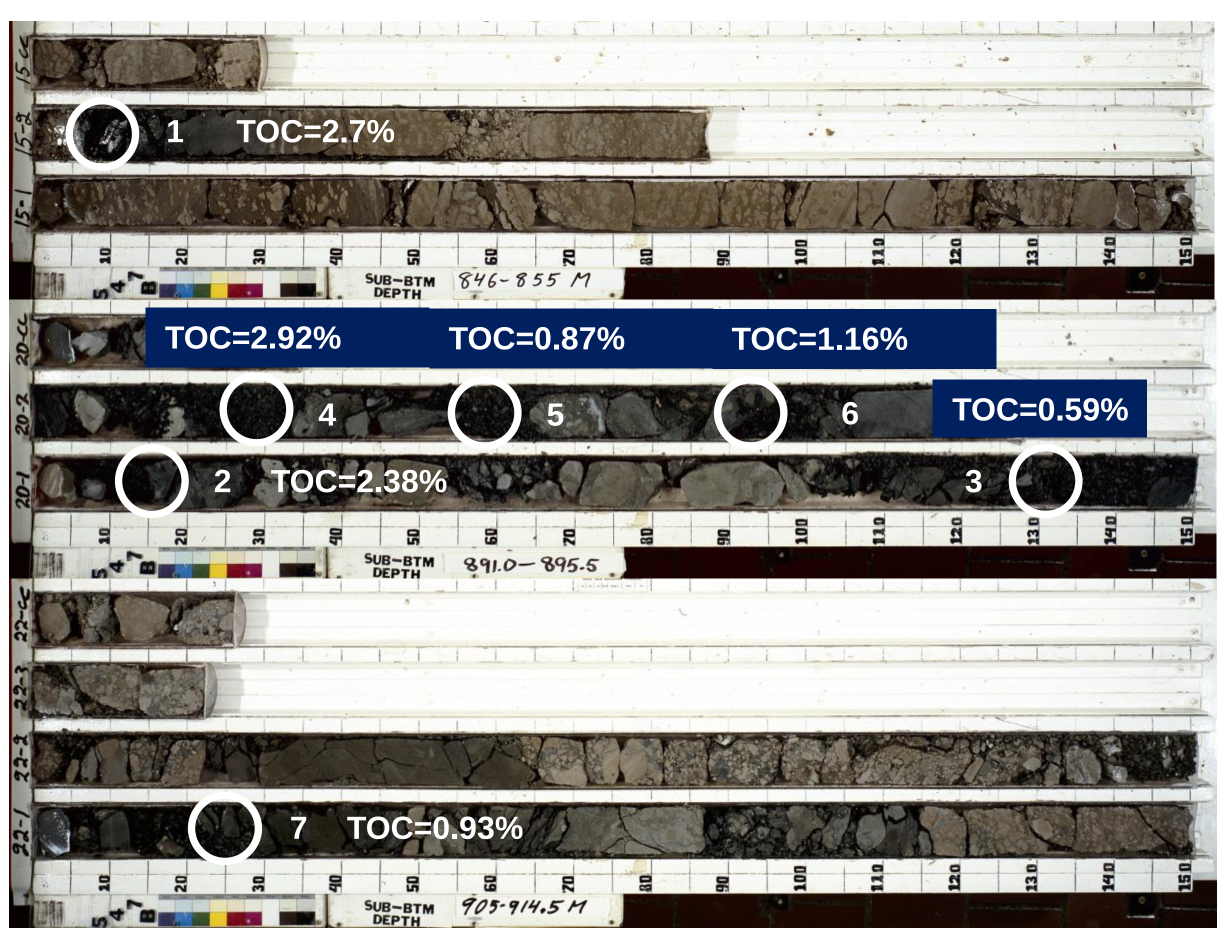


Figure 5: Picture of the cores from DSDP well 547B. The spots where the samples were collected from are outlined by circles. TOC are from the data listed in Table 2

Gammacerane quasi absent in the Early Jurassic of DSDP well 547B

- ✓ The Early Jurassic offshore Morocco, DSDP Leg 79 Site 547, consist of black shale associated to a carbonate environment of deposition without signs of hypersalinity (Figures 2 & 4).
- ✓ The Triassic section of the well 547B consists of red beds as shown in Figure 2 and Map in Figure 7 (Eurydice equivalent on the Nova Scotia margin).
- ✓ Consistently, the hopane traces (ion 191) of extracts from several black shale samples collected and analyzed for this study display very lean Gammacerane content only, nothing more than a usual background (see below Figure 6).
- ✓ Gammacerane is a proof of the existence of an Early Jurassic source rock. Its absence does not indicate the absence of an Early Jurassic source rock but the absence of hypersaline (or water stratified) environment of deposition.

References:
J. Rullkotter, P. A. Mukhopadhyay, R. G. Schaffer, D. H. Welte (1984). Geochemistry and petrography of organic matter in sediments from Deep Sea Drilling project Sites 545 and 547, Mazagan Escarpment.
Hinz K., Winter E. L., Baugartner P. O., Bradshaw M. J., Channel J. E. T., Jaffrezo M., Jansa L. F., Leckie R. M., Moore J.N., Rullkotter J., Schaftenaar C., Steiger T. H., Vuchev V. and Wiegand G. E. (1982). Preliminary results from DSDP Leg 79, seaward of the Mazagan Plateau off Morocco. *In* von Rad U., Hinz K., Sarnthein M. and Siebold E. (eds.), *Geology of the Northwest African Continental Margin:* Berlin-Heidelberg (Springer-Verlag), pp. 23-33.

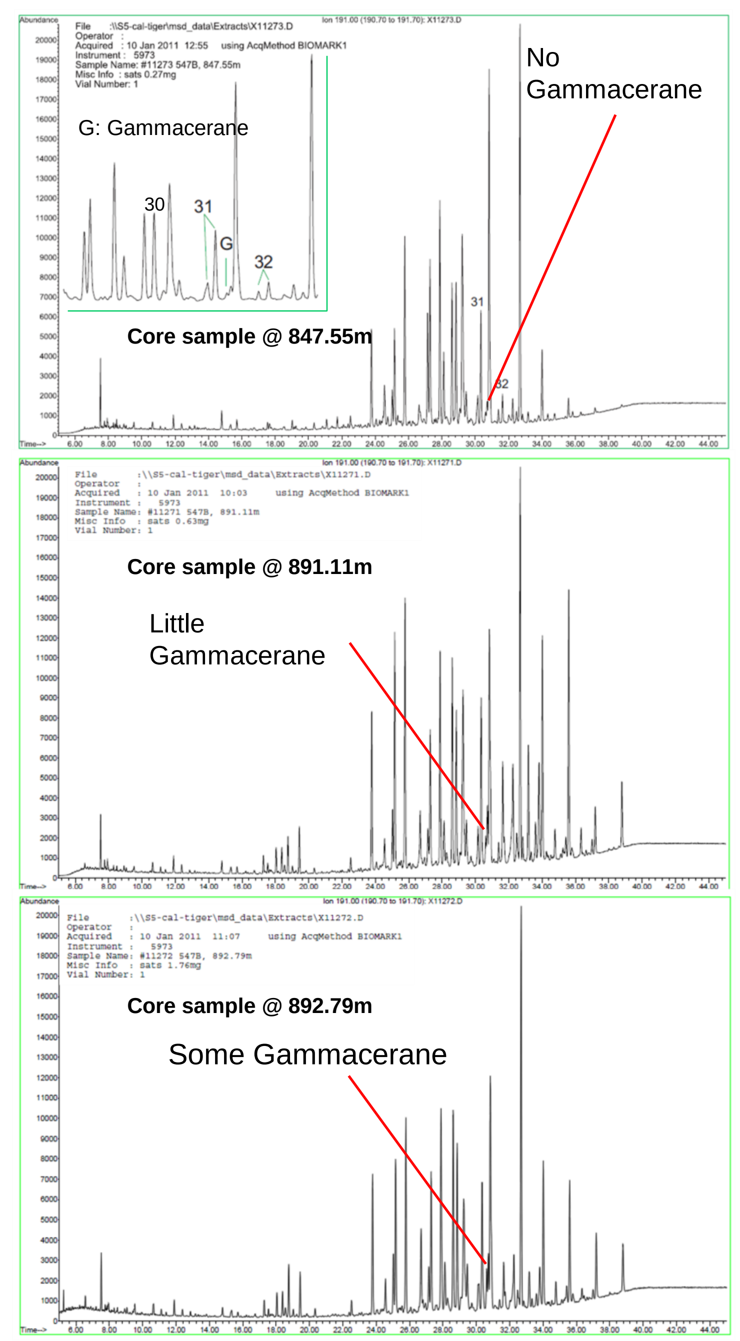


Figure 6: Ion 191 traces of three samples of Toarcian black shales from DSDP Leg 79 Site 547, well 547B. These traces display no or background abundance of Gammacerane. The shallow depth of these samples explains their immaturity and unusual signatures. Location, analytical results and geological context is presented in Figures 1, 2, 3, 4 and 5.

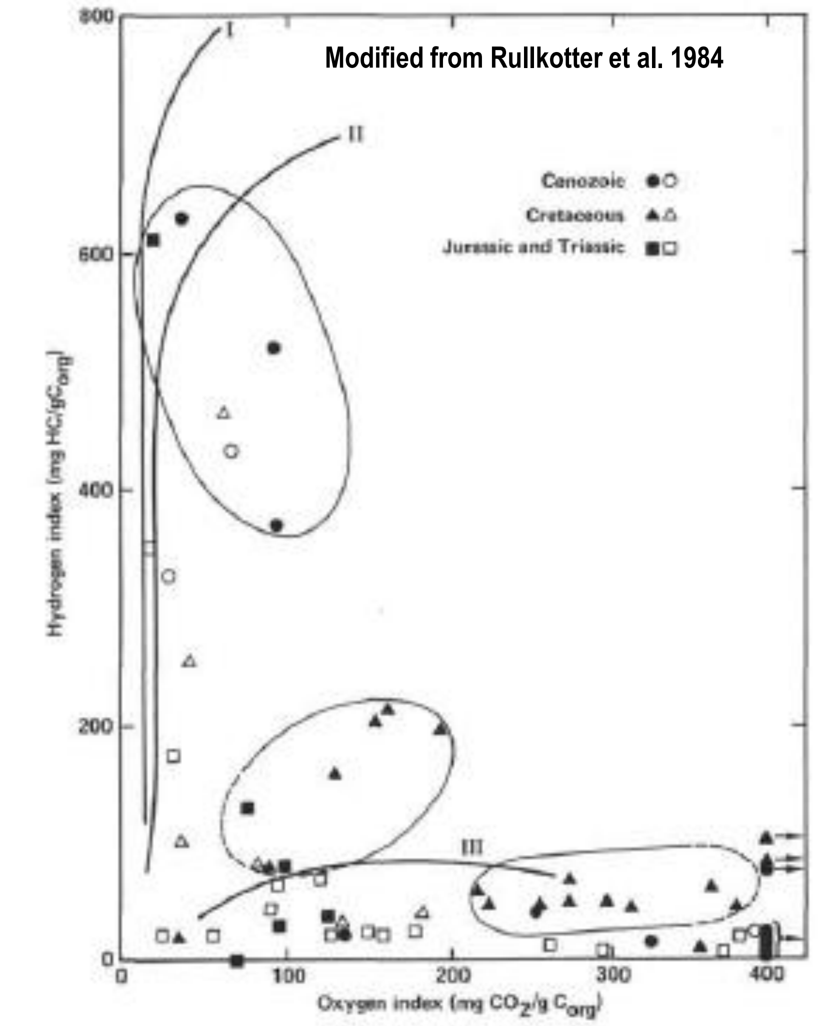


Figure 3: Hydrogen versus Oxygen indices from Early Jurassic rocks in DSDP well 547B

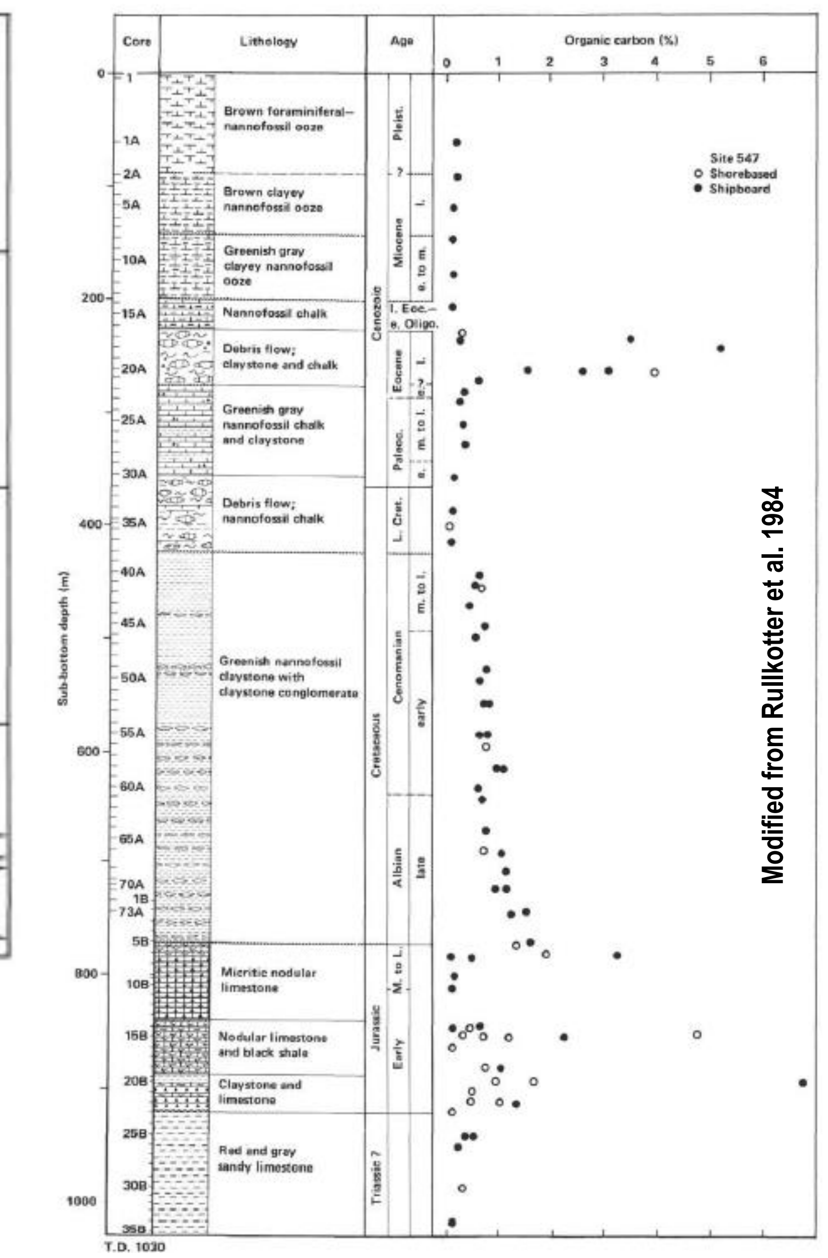


Figure 4: Total Organic Carbon measurements in DSDP well 547B

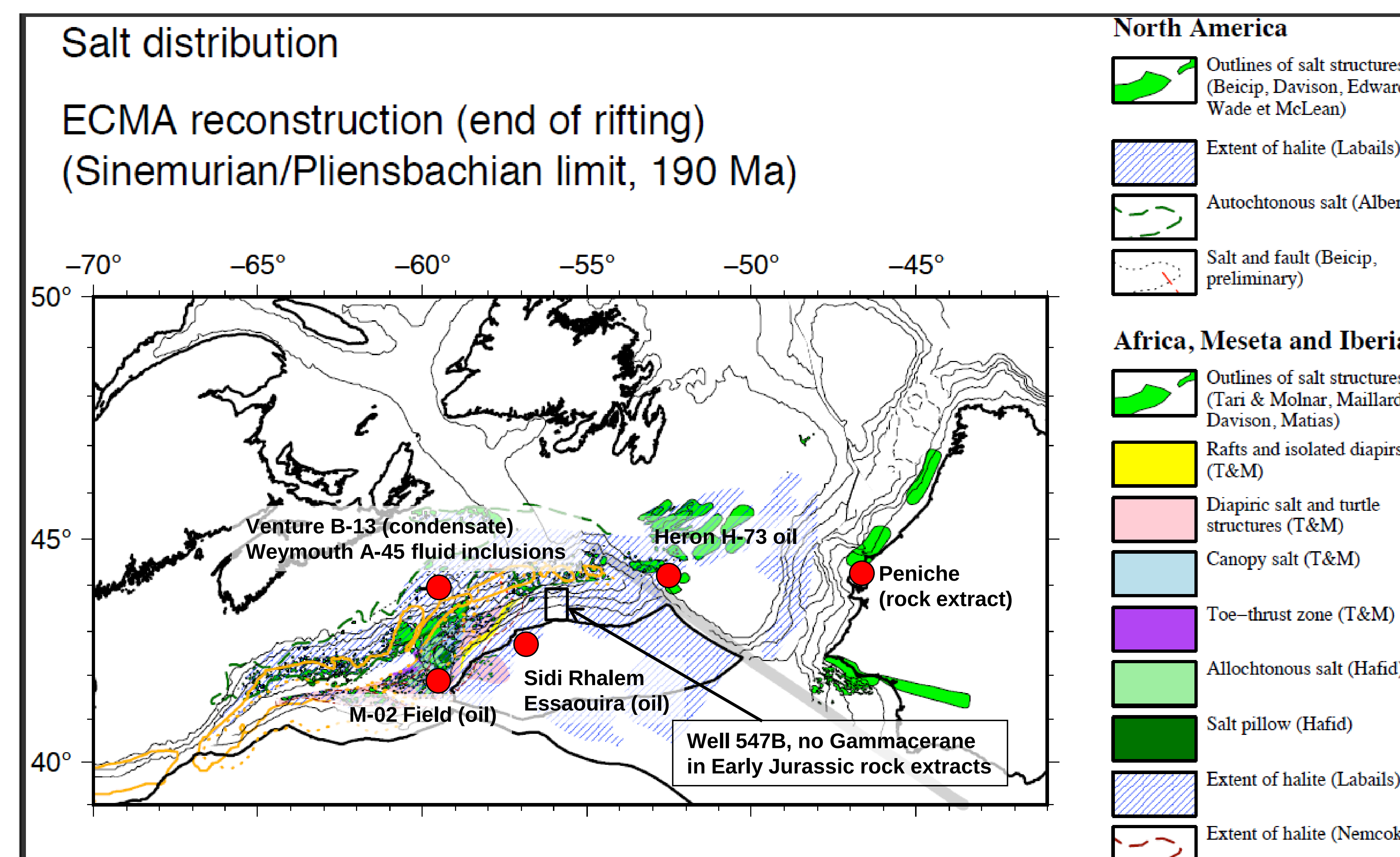


Figure 7: Rift reconstruction 190 Ma and salt distribution by Sibuet (2010). Red dots show locations of Gammacerane occurrences in oils, condensates, rock extracts and hydrocarbon fluid inclusions. Gammacerane is absent or in very low abundance in Early Jurassic organic-rich intervals of DSDP wells 547B. Also, there is no salt deposited in the Triassic/Jurassic interval of well 547B (Figures 2, 3, 4 and 5).

Gammacerane distribution

The most convincing Gammacerane occurrences supporting the existence of an Early Jurassic generative system are:

- **The Gammacerane observed in the fluid inclusions in the allochthonous salt of the Weymouth A-45 well on the Nova Scotia margin (Figure 1),**
- **The Gammacerane observed in the Pliensbachian source rock of the Peniche outcrop on the Portugal margin (Figure 2), and**
- **The Gammacerane observed in the oil of the Cap Juby M-02 and the Sidi Rhalem fields on the Moroccan conjugate margin (Figure 3).**

Fluid inclusions from Glooscap C-63 and Weymouth A-45

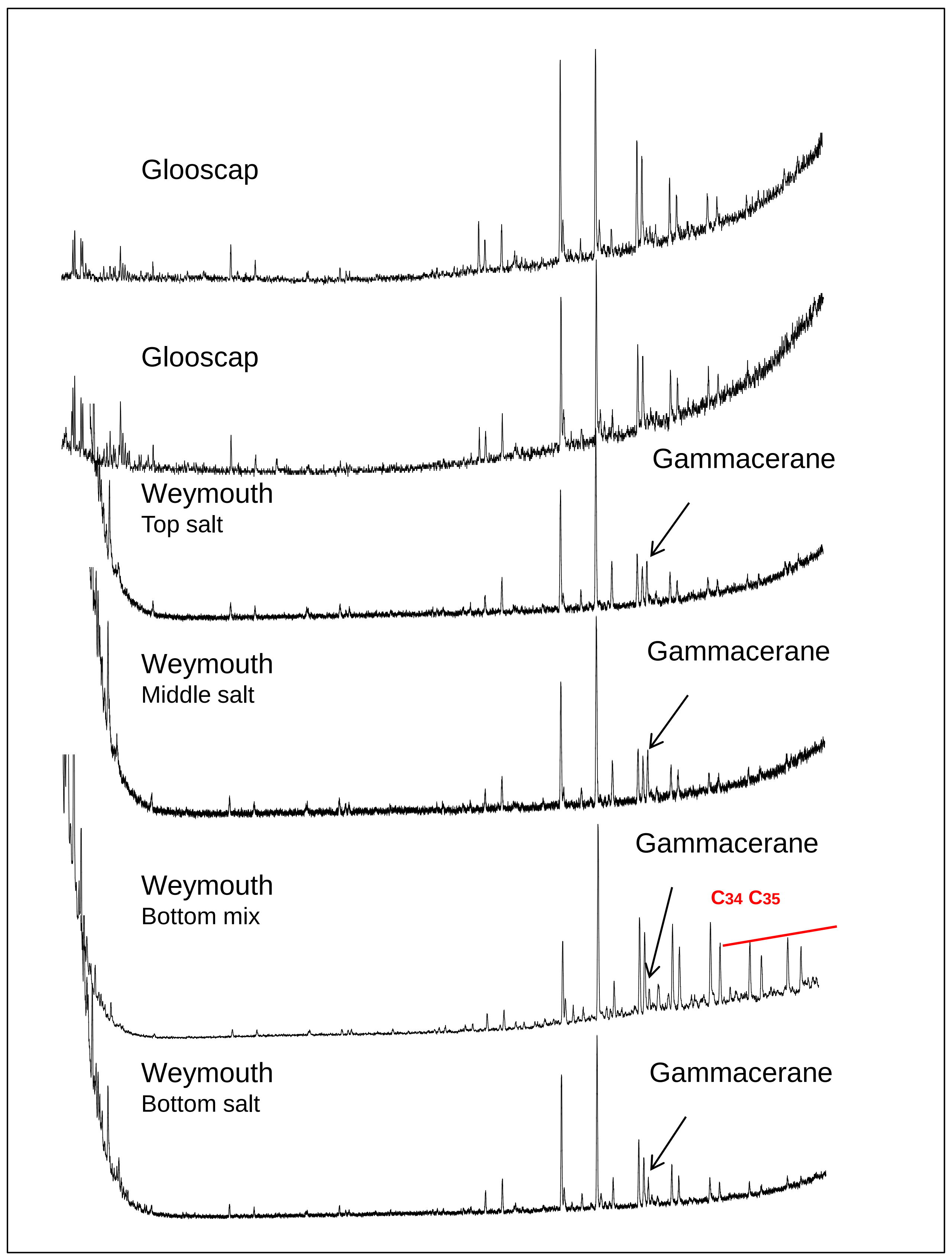
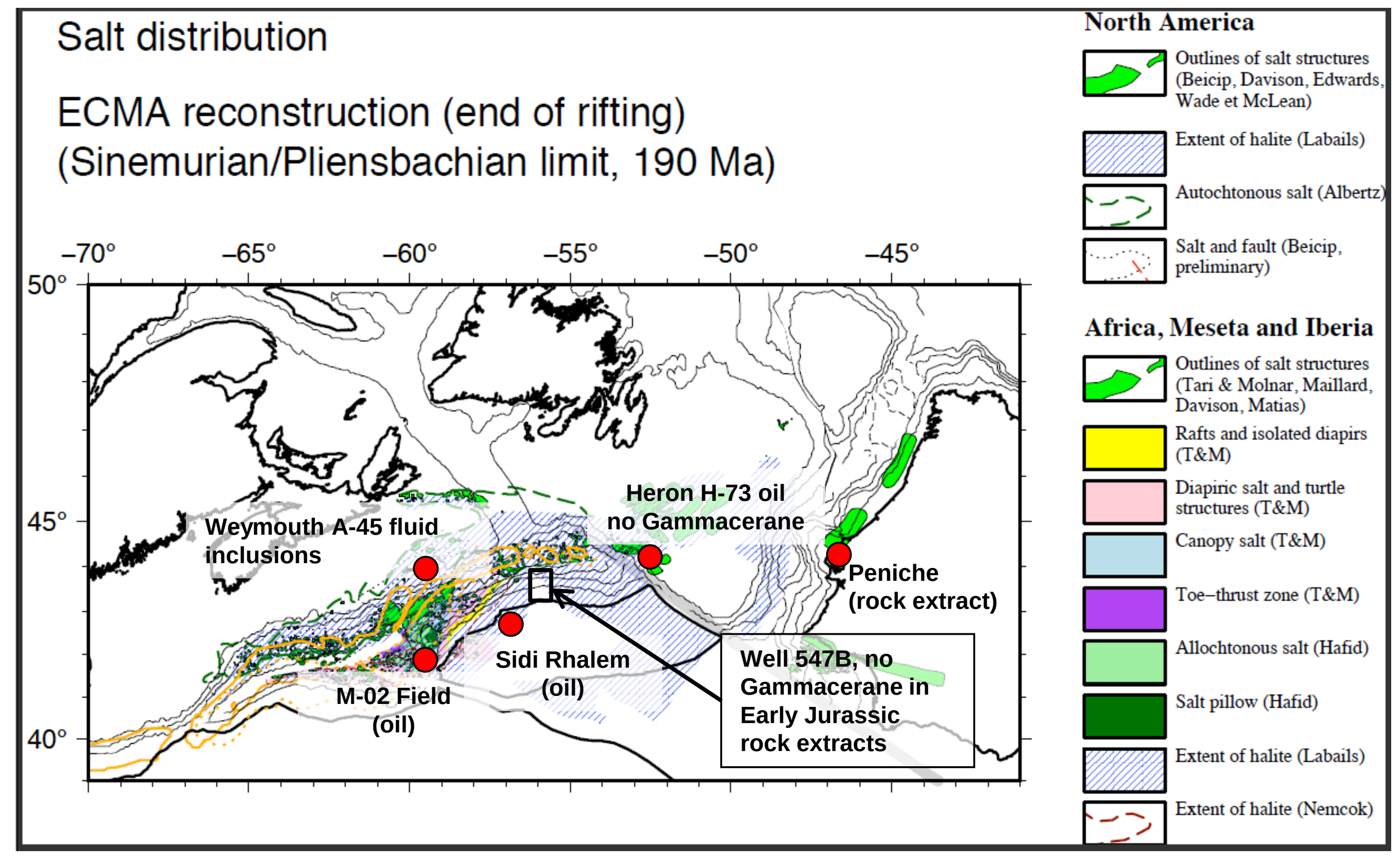


Figure 1: Hopane traces (m/z 191) of hydrocarbon (HC) fluid from inclusions in salt at show significant amount of Gammacerane in the salt canopy at Weymouth A-45. In the autochthonous salt at Glooscap C-63, there is no particular Gammacerane anomaly. In addition, in the Weymouth A-45 bottom mix gathering several samples from the basal part of the canopy, the homohopane ratio C_{35} to C_{34} equal to 1 suggests that the source rock of these HC inclusions deposited in a carbonate environment.



Locations of most convincing Gammacerane occurrences. Note that in the Heron and DSDP 547B wells Gammacerane is absent in the Early Jurassic source rock extracts.

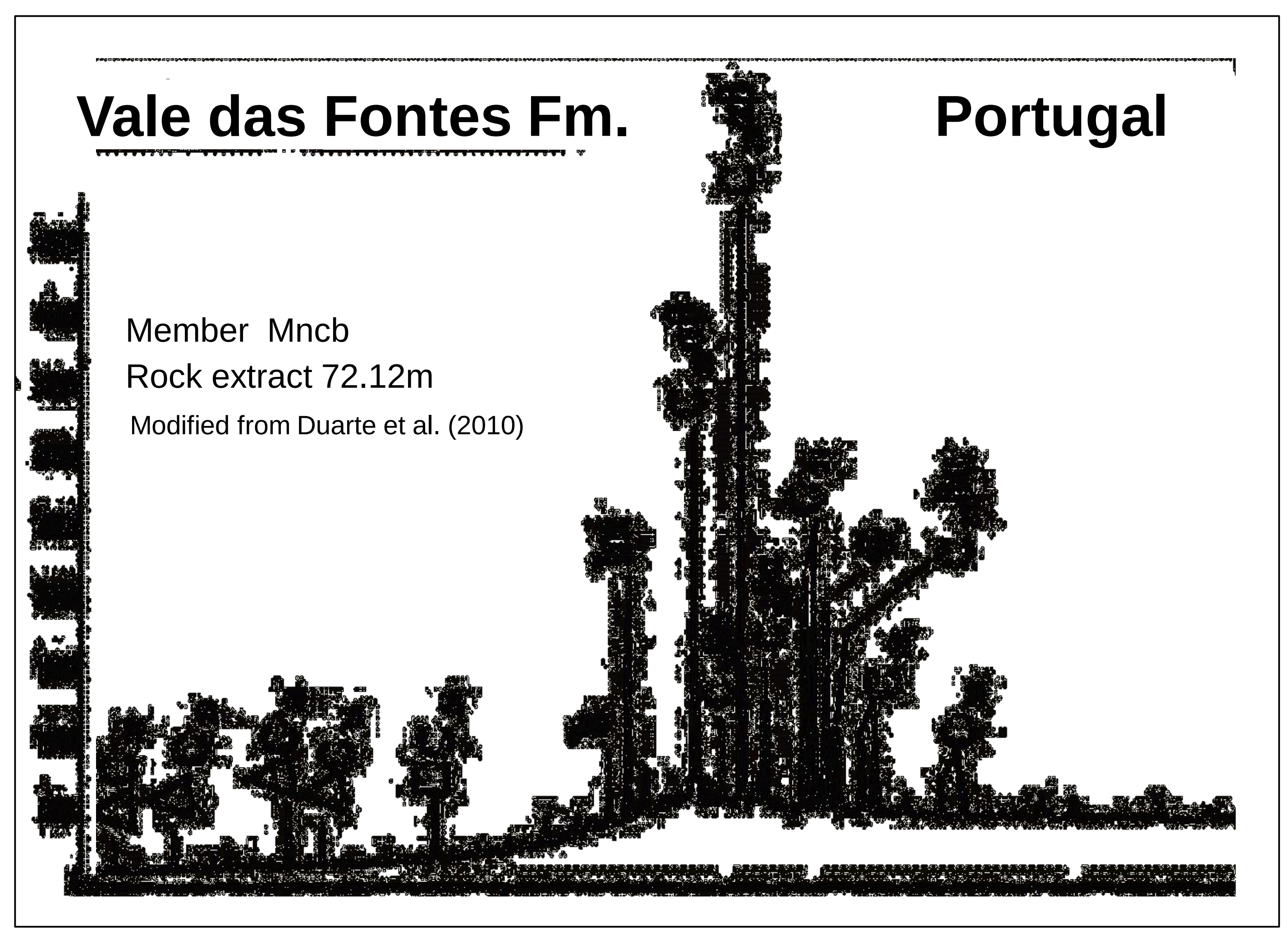


Figure 4:Biomarker traces (m/z 191). Gammacerane is present in an extract from the Mncb Member of the Pliensbachian Vale das Fontes Formation

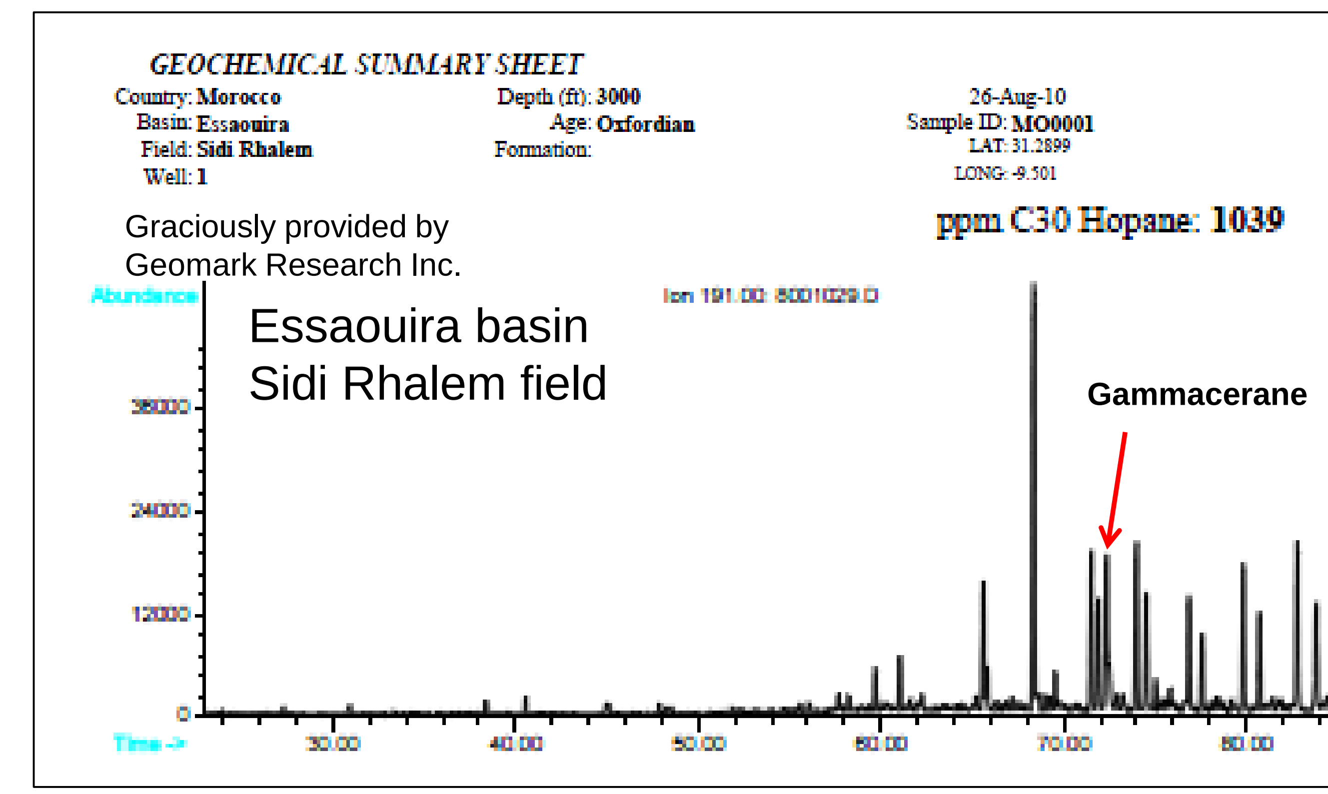


Figure 1: Biomarker traces (m/z 191). Gammacerane is present in the oil of the Sidi Rhalem field, Essaouira Basin, Morocco

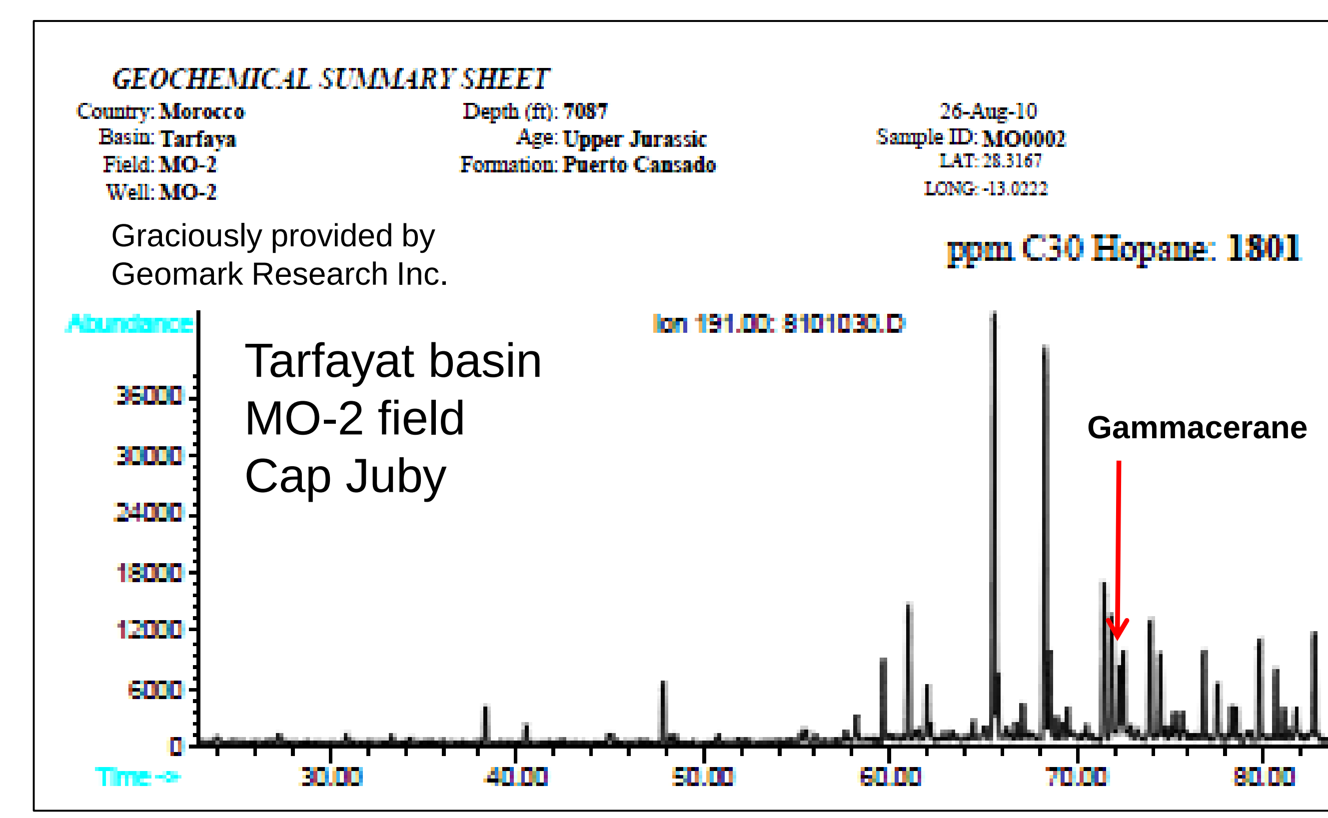


Figure 2: Biomarker traces (m/z 191). Gammacerane is present in the oil of the MO-2 field, Tarfayat Basin, Cap Juby, offshore Morocco

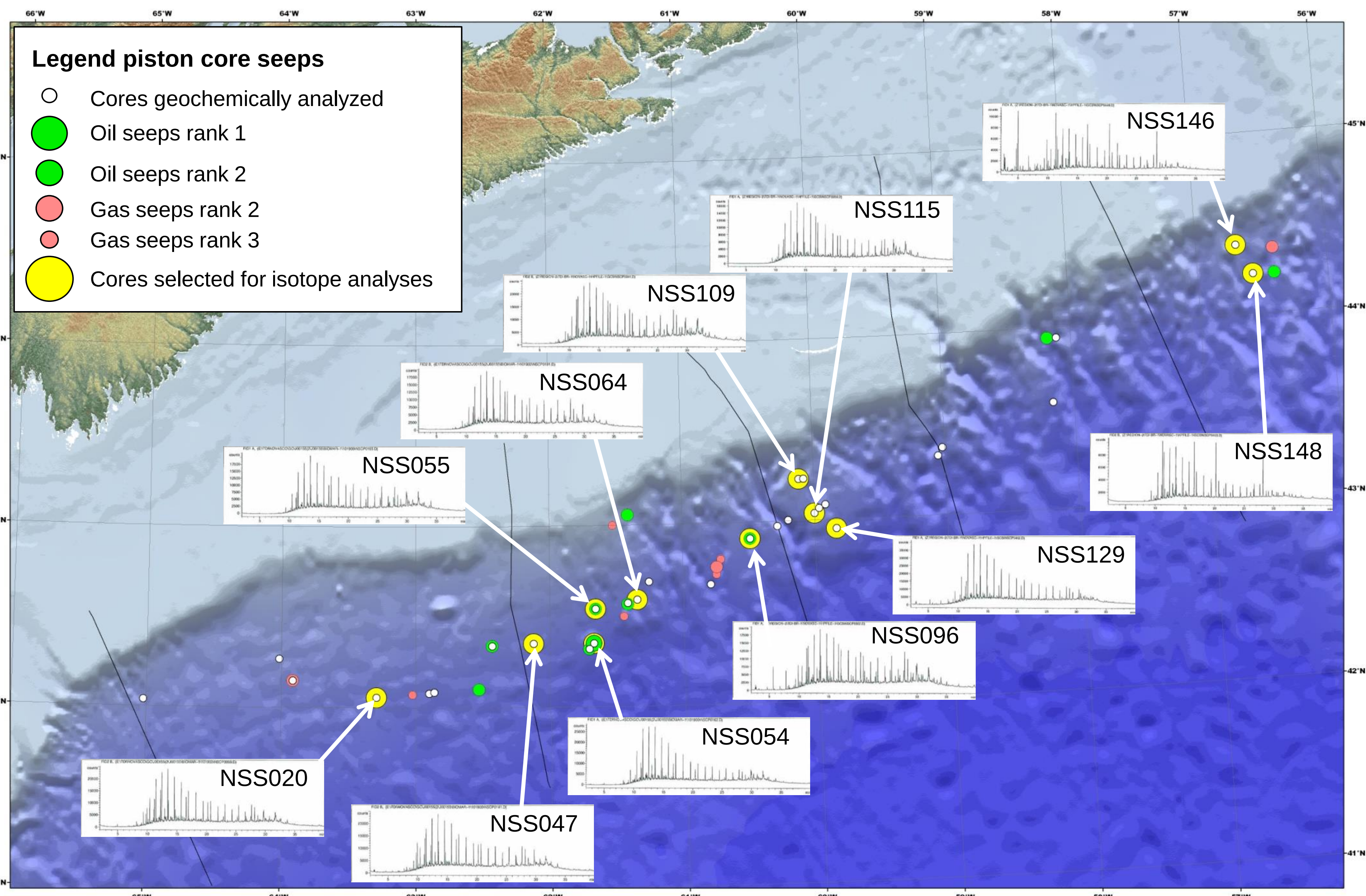


Figure 1: Location of the piston-cores analyzed for carbon isotopes (yellow dots). The gas-chromatograms show that the samples extracted from the piston-cores are as little as possible contaminated by recent indigenous organic material.

Re-interpretation of the "REGIONAL GEOCHEMICAL SURVEY for 2000 Nova Scotia Consortium SGE PROGRAM by TDI-Brooks International, Inc.

Carbon isotope data

This interpretation integrates carbon isotope data of oil/condensate and source rock extracts from Mukhopadhyay (1989 & 1990), and TDI-Brooks data (2000) on seeps from piston-cores and data from Morocco margin graciously provided by Geomark Research, Inc.. Yet many of the extracts do not qualify as source rock for the oil and condensates from the Nova Scotia margin (see Sofer diagram below), some do. Along the Sofer line (Sofer 1984), $\delta^{13}C$ of the source extracts lighter than oil/condensates suggest a lower maturity of the source samples analyzed.

The piston-core seeps displaying $\delta^{13}C$ ranging in the -30 to -31 per mil for the saturate fraction and -29 to -30 per mil for the aromatic fraction are isotopically lighter than the oil/condensate and their qualifying source rocks, indicating a different source rock for these oil-seeps.

Comparison with Morocco oils (see location Figure 2) known to originate from the Toarcian source rock suggests that the piston-core seeps could originate from an Early Jurassic source rock possibly present on the Nova Scotia margin:

- The oil from the Essaouira field of Sidi Rhalem is isotopically compatible with the piston-core seeps (Figure 2)
- The MO-002 oil from the Tarfayat Basin (Cap Juby; see location Figure 2) known to originate from the Toarcian source rock displays isotopic values apparently compatible with the bulk of the Nova Scotia oils and condensates yet its biomarker present characteristics of hypersalinity (gammacerane) of an Early Jurassic (Toarcian) source rock (see Plate *****). However, the MO-002 oil is severely biodegraded, which may be the reason for the drift of its isotopic composition toward heavier values.

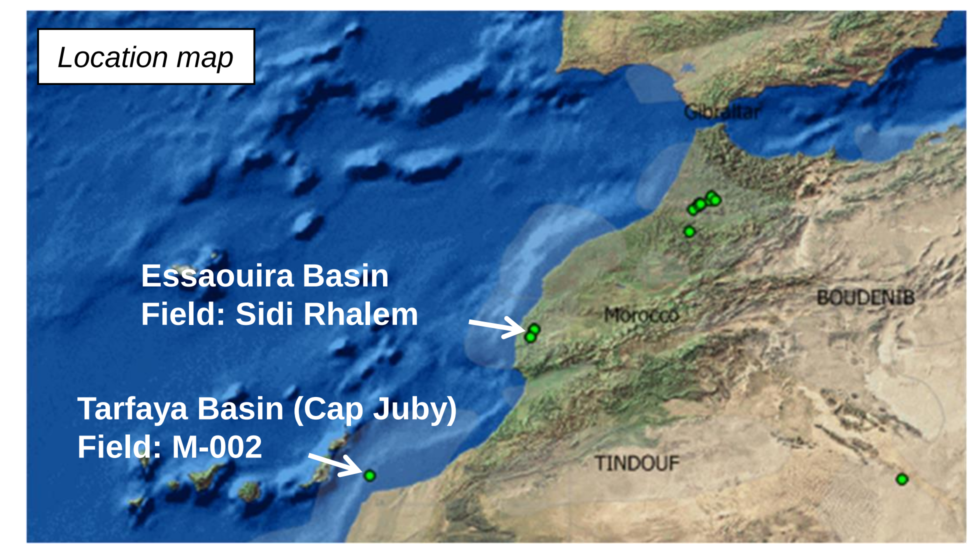


Figure 3: Location of the Morocco oil samples used for comparison of oils and condensates across the Atlantic ocean with the Nova Scotia conjugate margin

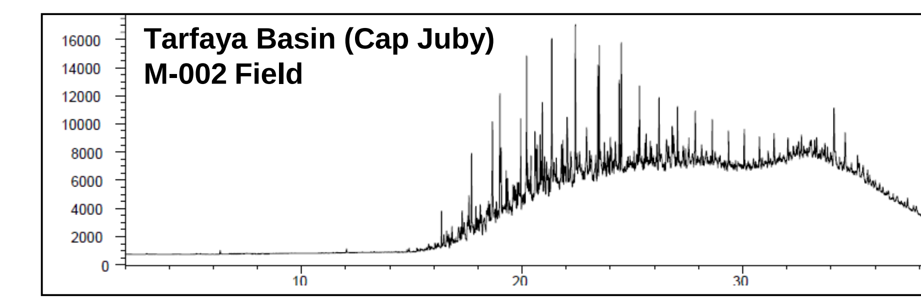


Figure 4: Gas-chromatographic trace of the MO-002 oil (Cap Juby, Tarfayat Basin) showing biodegradation of the oil.

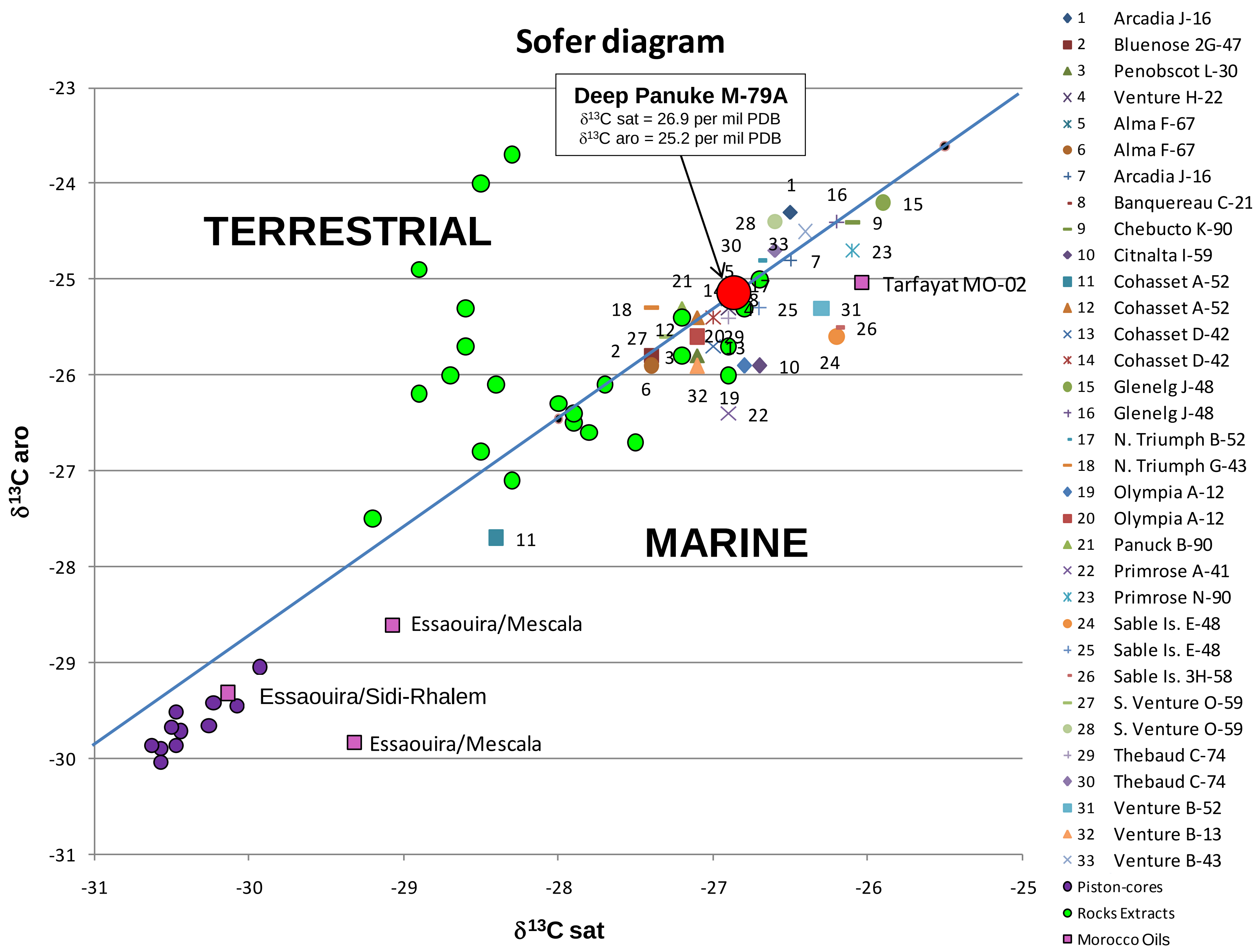


Figure 2: Sofer diagram (Sofer, 1984) displaying carbon isotopes (saturates & aromatics) of oils, condensates (numbered samples) and bitumen extracts from rock samples (green dots) from the Nova Scotia margin reported by Mukhopadhyay (1990). Piston-cores seeps (dark blue dots) from TDI-Brooks Int'l, Inc. study (2000) and Morocco oils) communicated graciously by Geomark Research are also included in the diagram. The Most of the Nova Scotia oils en condensates are located near the separation line between terrestrial and marine source origin. The bitumen extracts located near the line are candidates for sourcing the oils and condensates. Other extract located deep in the Terrestrial domain of the diagram can be discarded as source of the Nova Scotia oils and condensates. The piston-core seeps originate from a very distinct source rock. The isotope correlation of the piston-cores with Morocco Sidi Rhalem and Cap Juby MO-02 oils known to be sourced from the Toarcian source rock supports the presence of an Early Jurassic source rock on the Nova Scotia margin (conjugate to the Morocco margin). The MO-02 oil does not plot with the piston-core group but the new data point from Deep Panuke M-79A exhibits a $\delta^{13}C$ aro = 25.2 per mil PDB comparable to MO-02. The difference in saturates could be due to biodegradation of the MO-02 oil.

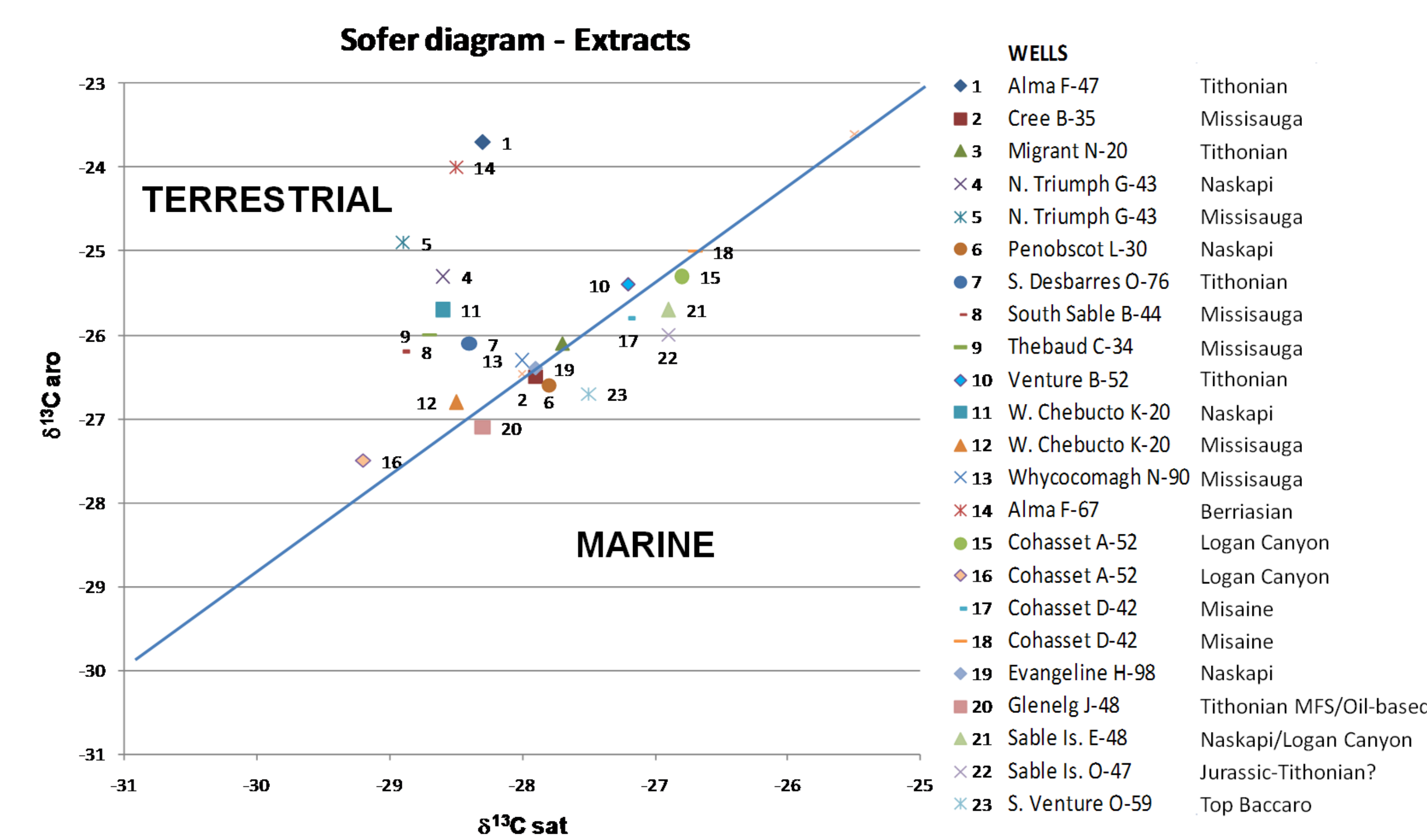


Figure 4: Sofer diagram (Sofer, 1984) displaying carbon isotopes (saturates & aromatics) of bitumen extracts from rock samples (green dots of Figure 2) selected from various wells and stratigraphic intervals. Only the bitumen extracts located near the line are candidates for sourcing the oils and condensates of the Nova Scotia margin.

References:
Mukhopadhyay P. K. 1990 Characterization and maturation of selected oil and condensate samples and correlation with source beds. Report, to Scientific Authority, Jon A. Wade. Bedford Institute of Oceanography. Dartmouth, Nova Scotia
Sofer Z. (1984) Stable carbon isotope compositions of crude oil: application to source depositional environments and petroleum alteration. American Association of Petroleum Geologists Bulletin, 68, 31-49
Bernard B. B., Allan K. A. and McDonald T; J. (2000) Regional geochemical survey for 2000 Nova Scotia Consortium. SGE Program. TDI-Brooks International, Inc. report, December 2000.

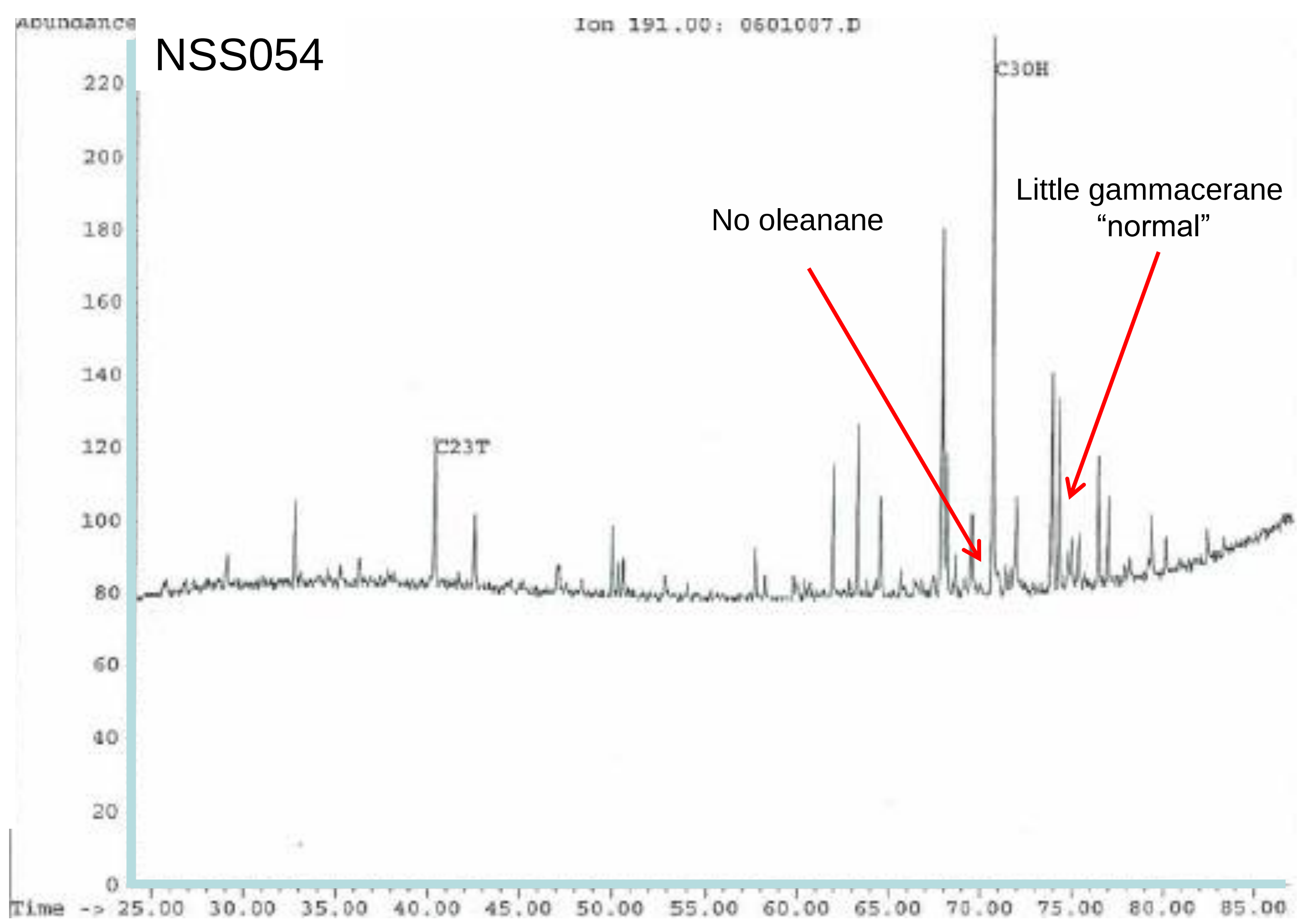


Figure 1: Low Gammacerane abundance in piston-core seeps

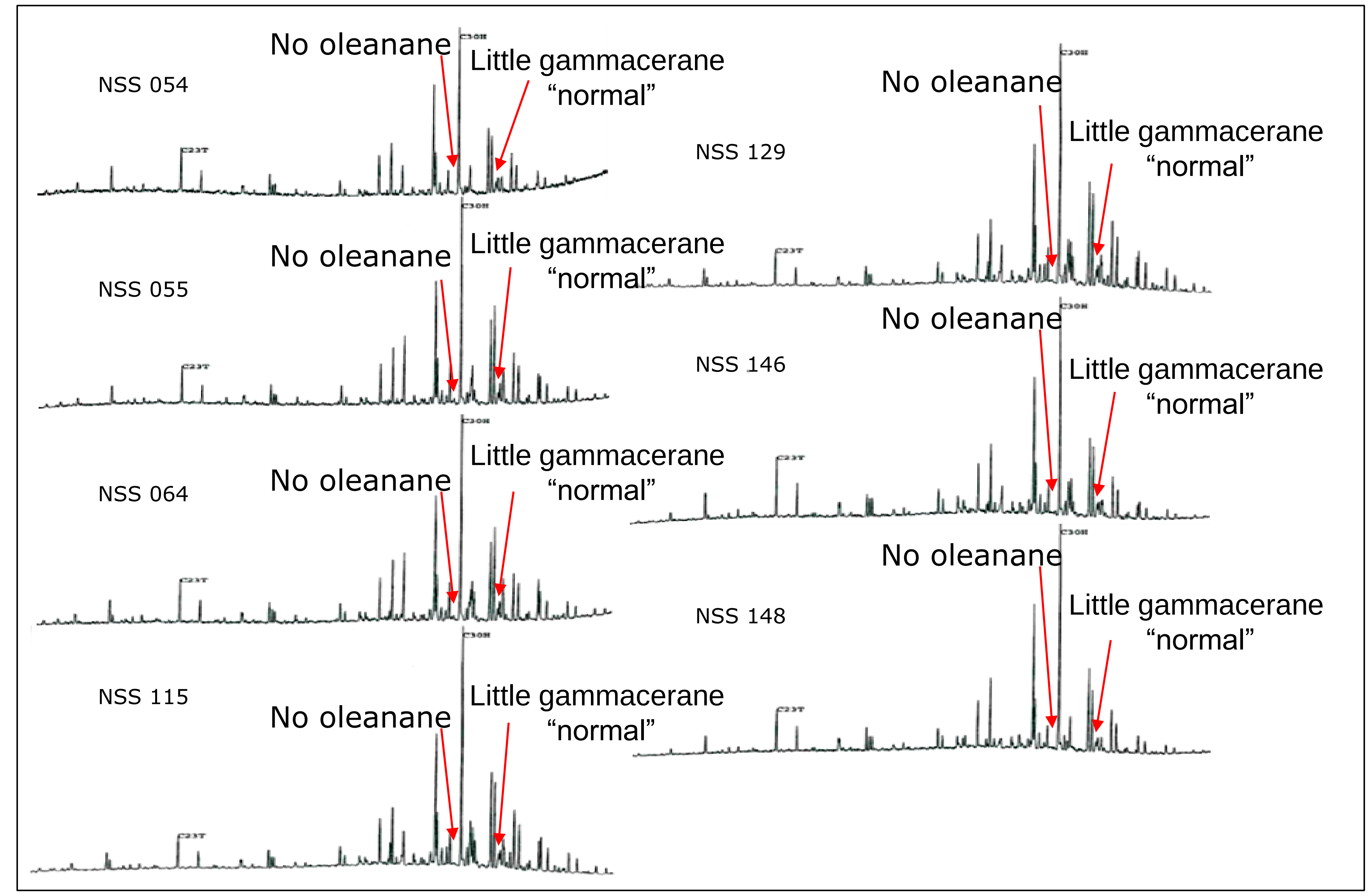


Figure 2: Low Gammacerane abundance and absence of Oleanane in all piston-core seeps analyzed for stable carbon isotopes.

Piston core conclusions

- The tight isotope group (Figure 2, Plate 4-4-7b) formed by the piston core samples separates them clearly from the condensates of the Shelf gas discoveries and suggest that they are all originated from the same source rock
- Good match of the isotopic signatures with the Sidi Rhalem oil of Morocco sourced by an Early Jurassic (Pliensbachian/Toarcian) source rock (Figure 2, Plate 4-4-7b) suggests and supports the presence of an Early Jurassic source rock on the Nova Scotia margin.
- Gammacerane “normal” does not suggest hypersaline sourcing. Gammacerane is absent in the Toarcian source rock in the DSDP well 547B (see Figure 6, Plate 4-4-7a)
- Absence of Oleanane precludes any Late Cretaceous sourcing (Figures 1 & 2, this Plate 4-4-8a)

THESE ARGUMENTS SPEAK IN FAVOR OF PRESENCE OF AN EARLY JURASSIC SOURCE ROCK

- On the western part of the margin, under the slope, the Early Jurassic source rock is the only one mature.
- Going east, other source rocks become mature up to at least the Tithonian one, which could also feed the seeps.
- The effect should be to spread the tight isotope seep group toward the discovered oil/condensates group but this does not happen as if the Early Jurassic source rock was the only one feeding the seeps.

THIS OBSERVATION DOES NOT SPEAK AGAINST THE PRESENCE OF AN EARLY JURASSIC SOURCE ROCK BUT WEAKENS THE SIGNIFICANCE OF THE ISOTOPIC DATA FOR DEFENDING THAT CAUSE

PL. 4-4-8a

Source rock characteristics

Lower Cretaceous – Aptian (deltaic)

The source rock was deposited during the Intra-Aptian flooding event as a prodeltaic facies of the incipient Logan Canyon/Cree deltaic development. The source interval coincides reasonably well with the Naskapi shale of the lithostratigraphic nomenclature. TOC/Rock Eval data defining the characteristics of this source rock are shown in Plate 5.4.2 for various wells from the Scotian Shelf and Slope. Organic richness is only fair with TOC averaging 2%. The organic matter composing this source rock is of a terrestrially derived Type III as is suggested by microscopic kerogen analyses and Hydrogen Index – Oxygen index cross plots shown in Plate 5.4.2.

The hydrocarbon kitchen applying to the Aptian source rock is practically never mature enough on the shelf to generate hydrocarbons. The maturity data (Vitrinite Reflectance) for various well locations indicate mostly immaturity except for wells located at present day shelf edge, e.g. Chebucto K-90. As a consequence of the limited kitchen, the Naskapi source rock does not appear to be a large contributor to the petroleum system of the Nova Scotia margin.

For modeling purpose, the Naskapi source rock is defined as follows:

- TOC=2%
- Kerogen Type III, using default Type III from Temis.

Lower Cretaceous – Berriasian (deltaic)

The age of this source interval is Berriasian-Valanginian (from K137 up) depositing as prodeltaic and paralic facies of the “middle” Missisauga delta. The Lower Cretaceous source rock is absent on the Jurassic carbonate shelf edge. That source interval is diffuse. Organic richness is mostly limited to TOC<1.5% and the kerogen is of a Type III. Plate 5.4.3 displays the characteristics of the Berriasian-Valanginian source rock.

The main reason for defining this interval as a source rock is to test its effect on the petroleum system modeled with Temis.

For Temis petroleum system modeling, the following characteristics are applied:

- TOC=2%
- Kerogen Type III, using default Type III from Temis.

Upper Jurassic – Tithonian MFS (carbonate transition to deltaic)

The Upper Jurassic source rock is present beyond the Jurassic carbonate bank edge. It was deposited at the transition from carbonate to deltaic environments of deposition during the Tithonian maximum flooding event. The source rock of the Tithonian MFS defined here corresponds to the lower part of the Verrill Canyon formation cited as source interval in P. K. Mukhopadhyay reports and publications. This Upper Jurassic source rock was difficult to identify due to drilling with oil-based mud (Lignosulphonate, Gilsonite and others) at the approach of overpressures, which is almost always coincidentally with approaching the Jurassic. Oil-based mud contamination strongly affects TOC/Rock Eval data usually by improving the response of these measurements to anomalously high values. The best and only way to overcome the distortion on Rock Eval analyses in defining source rock characteristics is to rely on kerogen microscopy, which allows for discriminating at least solid contaminants. In that regard, Mukhopadhyay’s work through the years is key for defining the Tithonian MFS as a prominent source rock of the deltaic region of the Nova Scotia margin.

Plate 5.4.4 displays the characteristics of the Tithonian source rock in various wells of the margin. South Griffin J-13 was not screened by kerogen microscopy,.

For Temis petroleum system modeling, the following characteristics are applied:

- TOC=5%
- Kerogen Type II-III.

Middle Jurassic – Misaine - Callovian MFS

Evidence for a Callovian source rock is limited to one well - Abenaki J-56 - located at the edge of the Jurassic platform. The extension of this source rock beyond the carbonate platform edge is unknown. In lithostratigraphic terms, this source rock corresponds to the Misaine Member. The Misaine is a shale dominated layer deposited during the Callovian flooding event. After Mukhopadhyay (1989), the Misaine in the Cohasset D-42 well is of Type III to IIB. In the new stratigraphic framework of this study, the source rock interval coinciding to the Callovian MFS is restricted to the part showing a kerogen Type IIB that is condensate/gas prone in Mukhopadhyay classification. Plate 5.4.5 displays the characteristics of the Callovian source rock in the Abenaki J-56 well, where it was penetrated and showed significant source potential.

For Temis petroleum system modeling, the following characteristics were applied:

- TOC=3%
- Kerogen Type IIB (II-III; standard)

Early Jurassic Source Complex - Sinemurian-Pliensbachian-Toarcian

A Sinemurian-Pliensbachian-Toarcian source complex was inferred by analogy to source rocks recognized on the conjugate margins of Newfoundland and Nova Scotia, in Portugal and Morocco. The Sinemurian immediately overlaying the Argo salt would offer a confined hypersaline environment, where source rocks are known to have deposited in rift basins. These confined environments are often prone to the development of ciliate bacteria, which are precursors of the Gammacerane molecule. Gammacerane was seen in the Pliensbachian source rock of Portugal (Peniche Basin) and in Moroccan oils. On the Scotian Shelf, one condensate from DST#6 of the Venture B-13 well and hydrocarbon fluids from salt inclusions in the Weymouth A-45 well display the presence of Gammacerane. Usually, DST hydrocarbon fluids are clean from mud contamination. However, if mud with Gilsonite additive was used and the formation tested was partly invaded by mud before testing, there is a chance that the DST fluids be contaminated. On the other hand, in the case of fluid inclusions in salt from the Weymouth well, the presence of Gammacerane is to be trusted as sample cleaning is drastic before crushing the inclusions for gas-chromatography (GC) and GC/mass-spectrometry (GCMS) analyses. The Toarcian penetrated in the 547B well of DSDP Leg 79, Site 547 did not display any Gammacerane leading to the conclusion that Gammacerane is not necessarily a criterion for defining the contribution of a Toarcian source rock. Depending on the environment whether hypersaline or not, Gammacerane may or may not be present. Along the Nova Scotia margin, Gammacerane may be associated to a source rock depositing at the end or immediately after the salt of the Argo Formation. At Pliensbachian and Toarcian time, the environment has possibly evolved into a carbonate environment no longer hypersaline or presenting any other water stratification of any type. This would be the case of the 547B well off Morocco, which penetrated the Liassic section down to a crystalline basement without penetrating any salt and not displaying any Gammacerane. In the Nova Scotia margin, the extension of a hypersaline source rock would be limited to the rift area occupied by the autochthonous salt of the Argo Formation. Later, once spreading had started, restricted conditions and hypersalinity ceased as the basin opened. Sediments could deposit further, beyond the autochthonous salt area, over the ECMA volcanics. Source rocks depositing then would no longer contain Gammacerane by lack of water stratification (halocline in this instance). In time succession, the hypersaline source rock would preferably be Sinemurian deposited approximately just before spreading. Then, source rocks depositing later during early spreading may lose hypersaline characteristics, these would be Pliensbachian – Toarcian in age. To summarize, one or more Early Jurassic source rocks may exist. Their presence is unproven but is worth considering based on the conjugate Moroccan margin.

For Temis petroleum system modeling, one source rock only is defined for the Sinemurian to Toarcian source complex with the following characteristics:

- TOC=5%
- Kerogen Type II

Source Rocks
of
the Laurentian Sub-basin

Geochemical Analyses

3 wells were sampled and submitted to Rock Eval and Vitrinite Reflectance analyses. Shows or recovered fluids were molecularly typed.

The objective was to review data for key Laurentian Channel wells and fill gaps in understanding using geochemical analysis as follows:

Identify & characterise potential Jurassic (or other) source rocks

- Rock-Eval screening analysis
- Molecular typing of shows or recovered fluids

Establish down-hole maturity trends

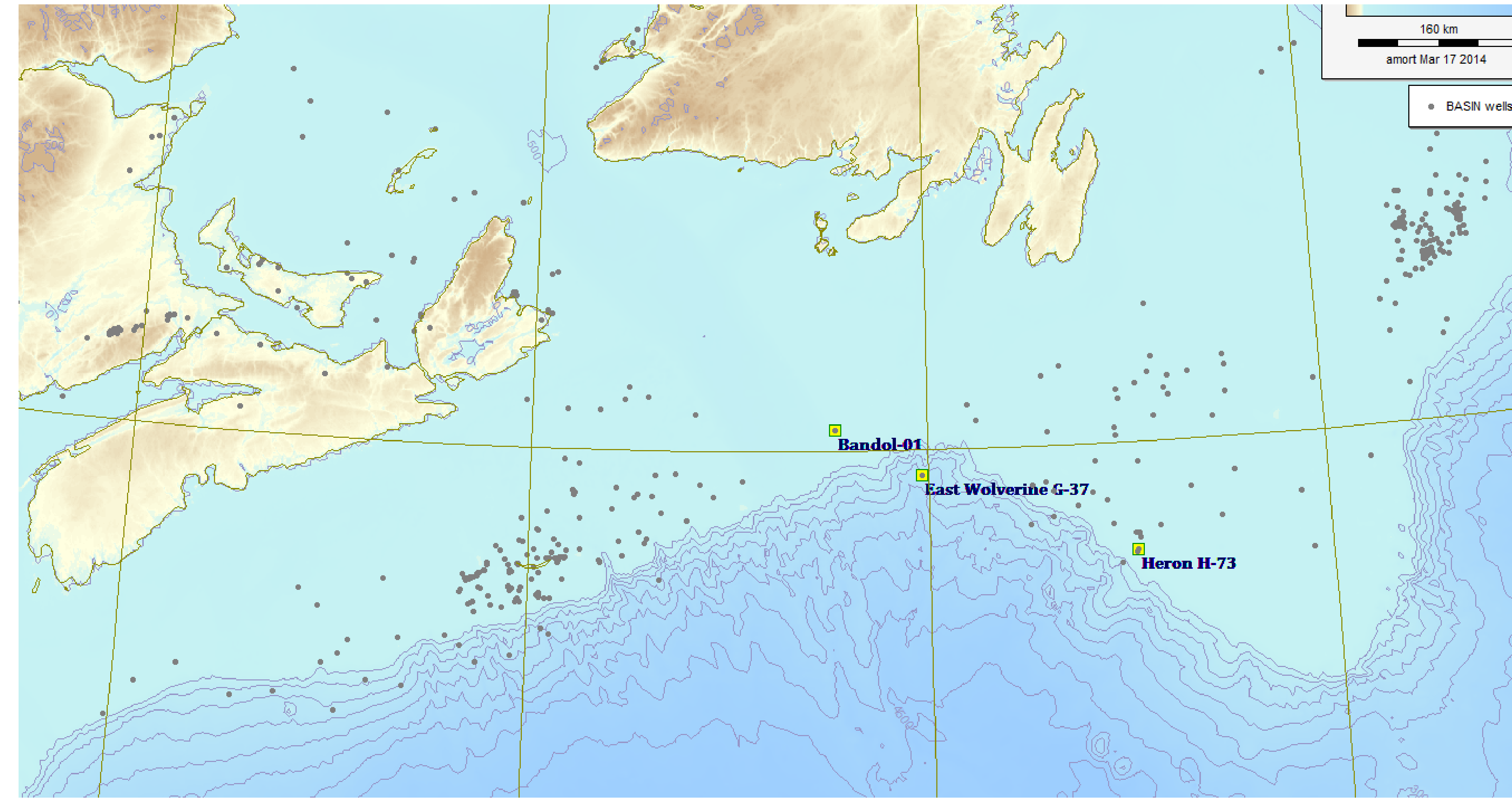
- Vitrinite Reflectance
- T_{max}
- Molecular maturity parameters in oils/extracts

Detect migrated hydrocarbons

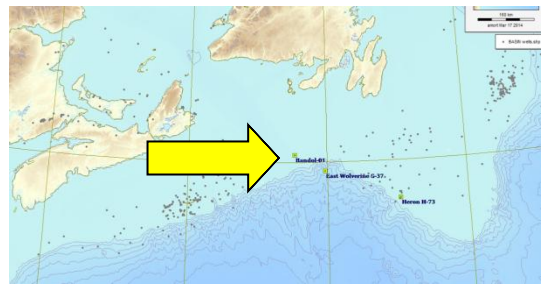
- Rock-Eval S1
- Extraction & GC
- Organic Petrography

If migrated hydrocarbons are present, what is(are) the likely source(s)?

- Molecular analysis of recovered hydrocarbons



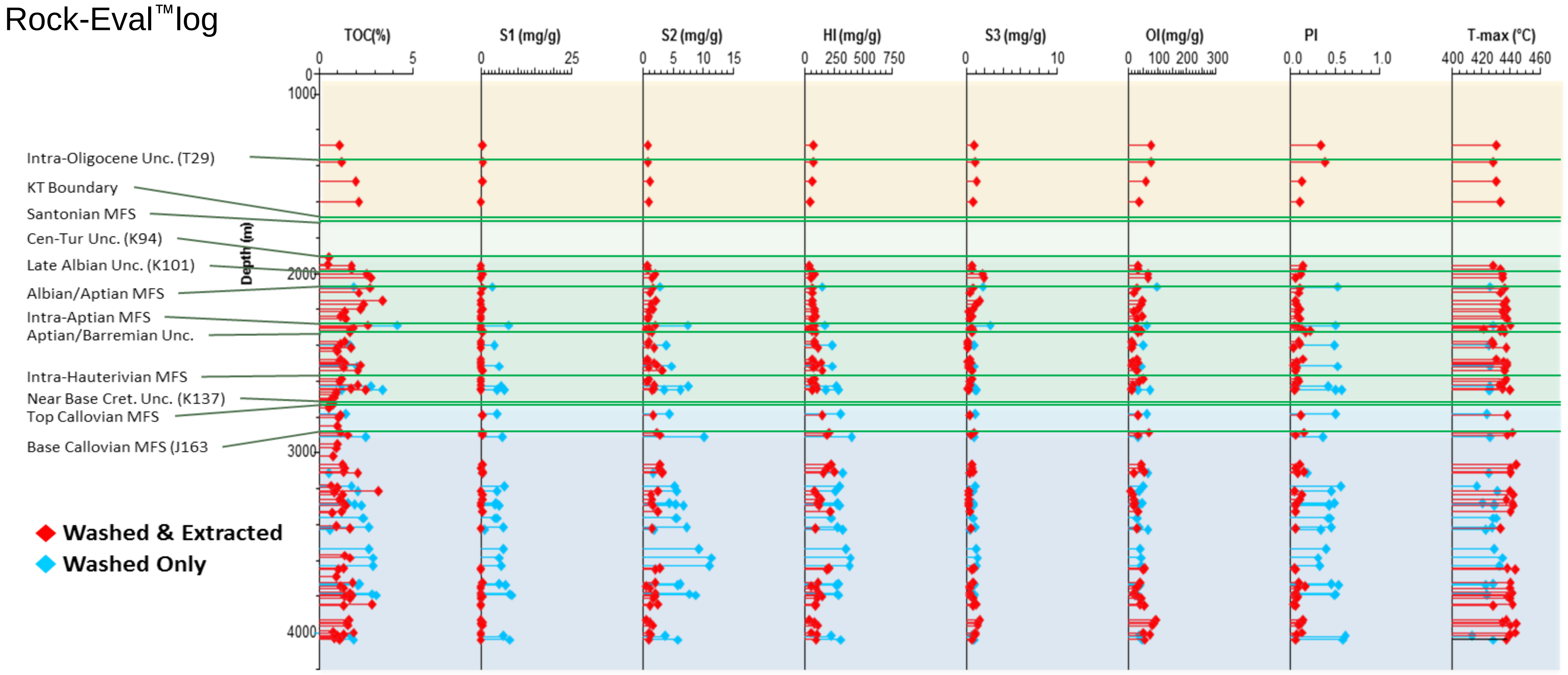
Well	Analysis						
	Rock-Eval	%VRo	Solvent Extraction	GC	SAT GCMS	ARO GCMS	Py-GCMS
Bandol-01	28 cuttings	-	6 cuttings	2 cuttings	-	-	-
East Wolverine G-37	95 cuttings	12 cuttings	12 cuttings	4 cuttings	4 cuttings	4 cuttings	1 cutting
Heron H-73	13 cuttings	4 cuttings	4 cuttings	4 cuttings, 1 oil	4 cuttings, 1 oil	4 cuttings, 1 oil	-



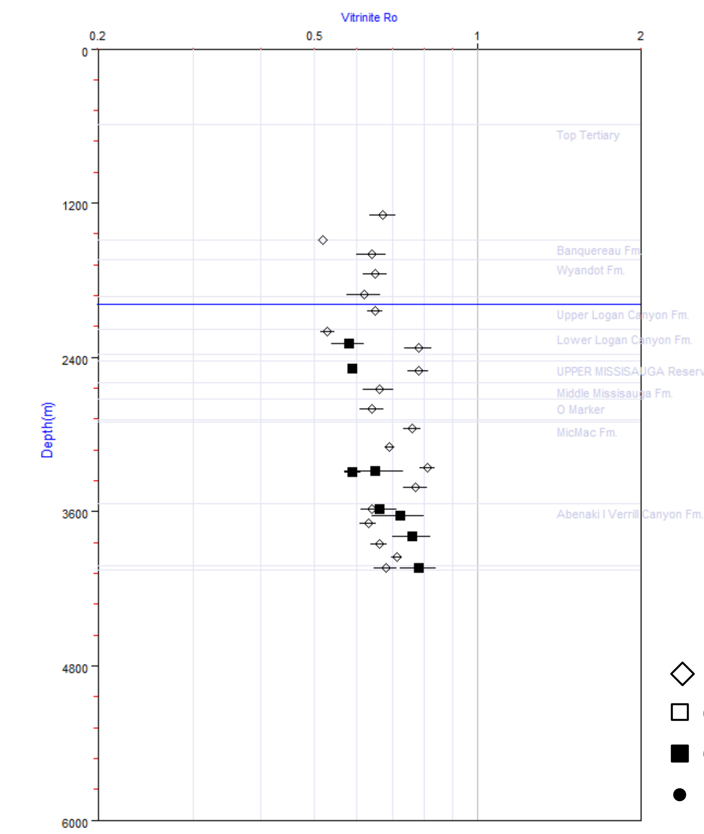
Bandol-01

The geochemical log for Bandol-01 highlights one of the primary problems in obtaining meaningful results from wells drilling with oil-based mud, particularly in this region. The red samples have been thoroughly washed and extracted and contain no useful information on generated hydrocarbons present, whether migrated or retained in source rock intervals. The blue samples have not been washed or extracted and show strong evidence of oil-based mud contamination (see PI values >0.5)

Rock-Eval™log



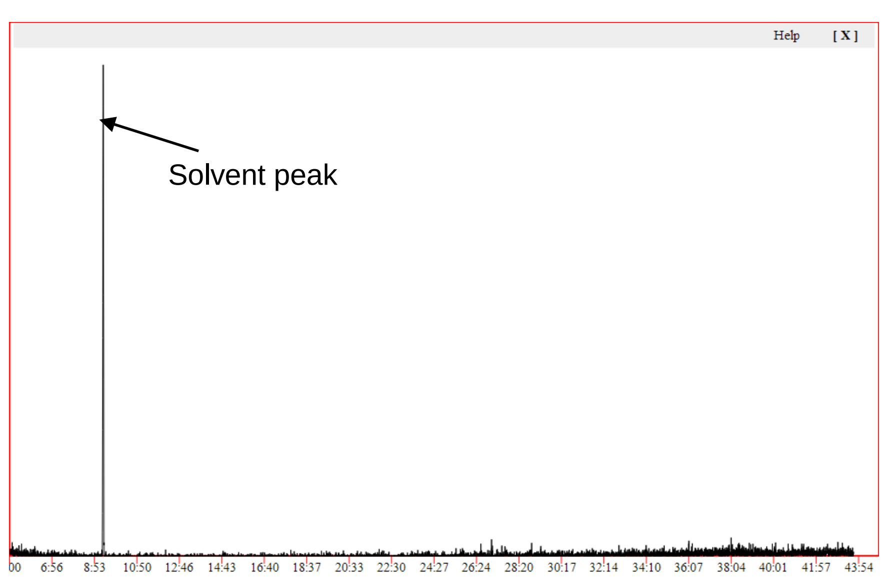
Maturity – Ro%



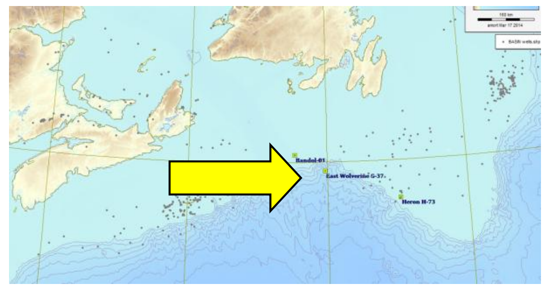
Bandol-01: Existing results (diamonds) inconclusive. New data (solid squares) still shows scatter but a maturity trend is discernible. Jurassic section is low maturity (0.7%VR_o)

◇ Operator (2001)
☐ Geochem Labs (1990)
■ GSC (2014)
• Avery (GSC, 1988)

Gas Chromatography



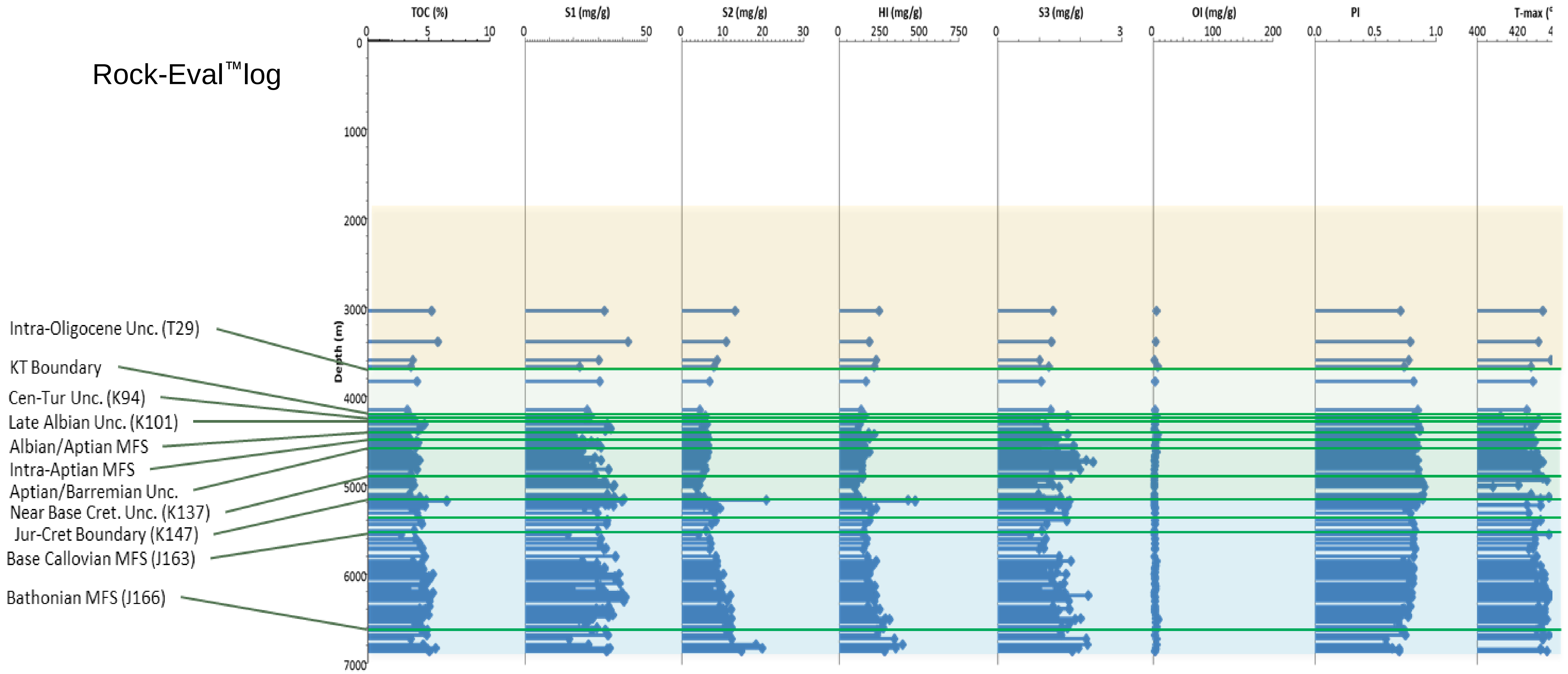
GC analysis of extracts in the Bandol-01 well yielded little of interest. Thermogenic hydrocarbons were notable by their absence.



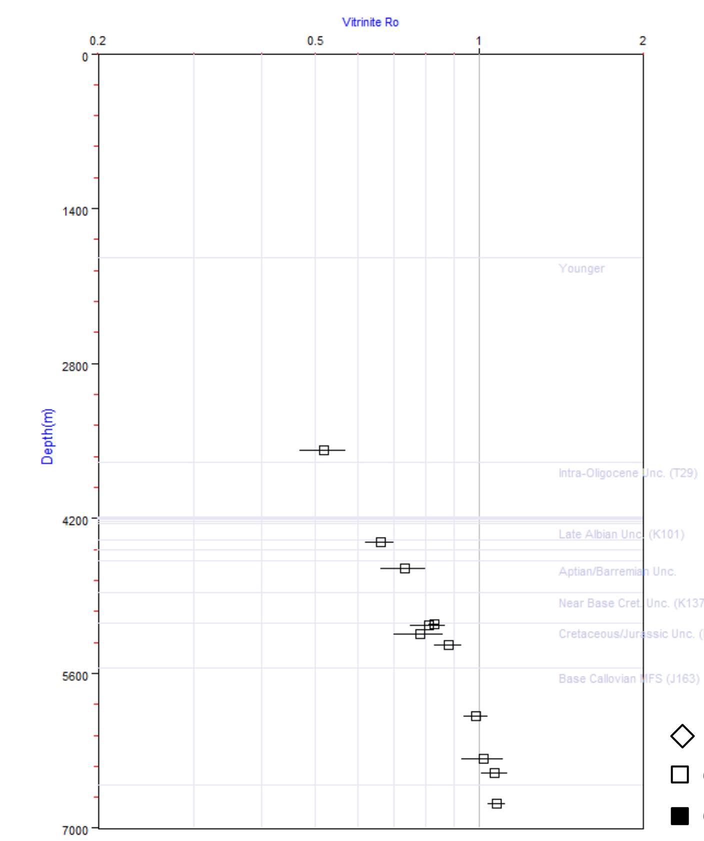
East Wolverine G-37

The interpretation of the East Wolverine G-37 well recently drilled that is the first deepwater slope location in this area and thus key to analyzing deepwater petroleum potential is severely compromised by drilling mud. Note the very high PI > 0.5 (Production Index). The Tmax maturity parameter also shows remarkably little observable variation. T_{max} picks were manually examined to eliminate analytical artefacts from the results which appear to reflect contamination rather than geological truth.

Rock-Eval™ log



Maturity – Ro%

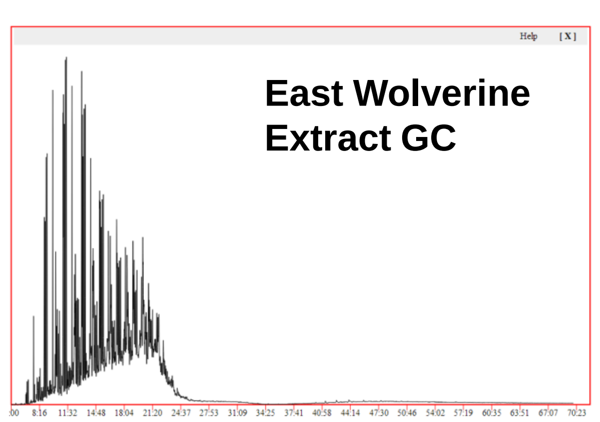


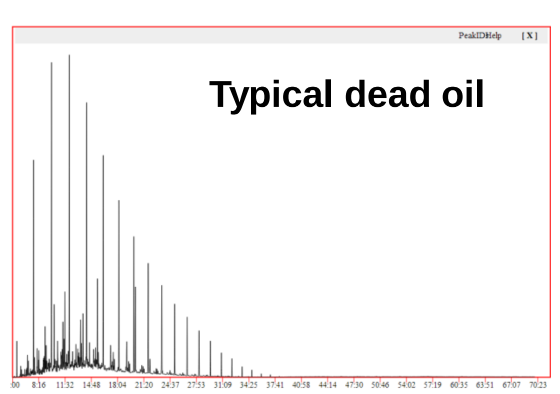
East Wolverine G-37: All new data. Much reworked organic matter but a valid downhole maturity trend is apparent. Middle Jurassic in the basal part of the well is in the late oil window (0.9-1.1%VR_o)

◇ Operator (2001)
□ Geochem Labs (1990)
■ GSC (2014)
• Avery (GSC, 1988)

Gas Chromatography

Gas Chromatography of a representative East Wolverine G-37 cuttings extract indicated that the dominant component is a component of the drilling mud system. Aromatic hydrocarbons are likely absent due to environmental regulation but the mud contamination contains more than just paraffins as shown by this GC.

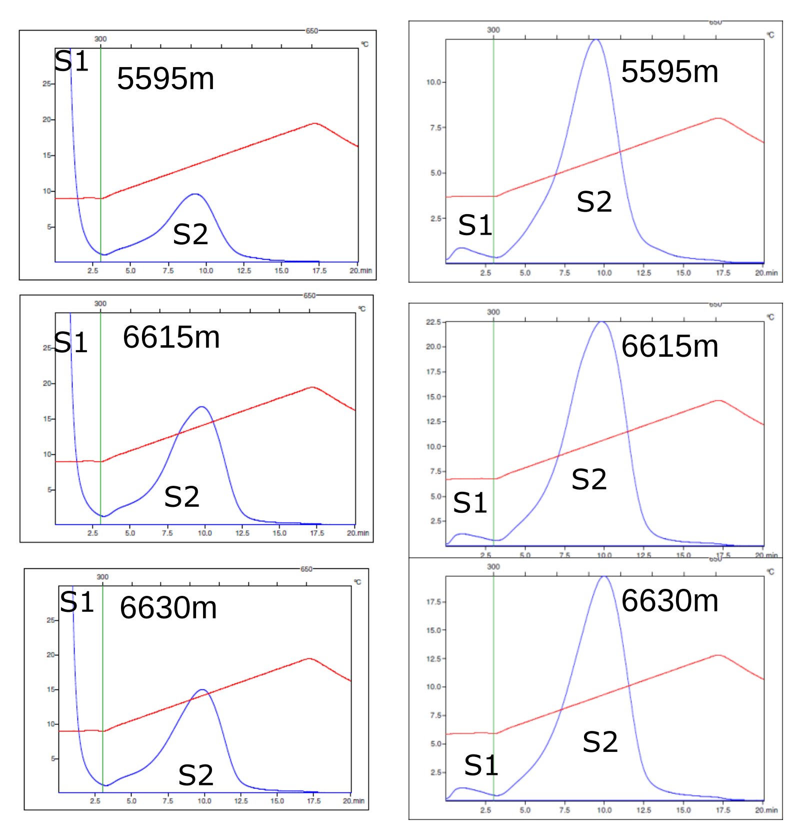




Neither fractionation by Al-Si column chromatography nor c18 Solid Phase Extraction (SPE) yielded a clean enough sample for interpretation of the GCMS

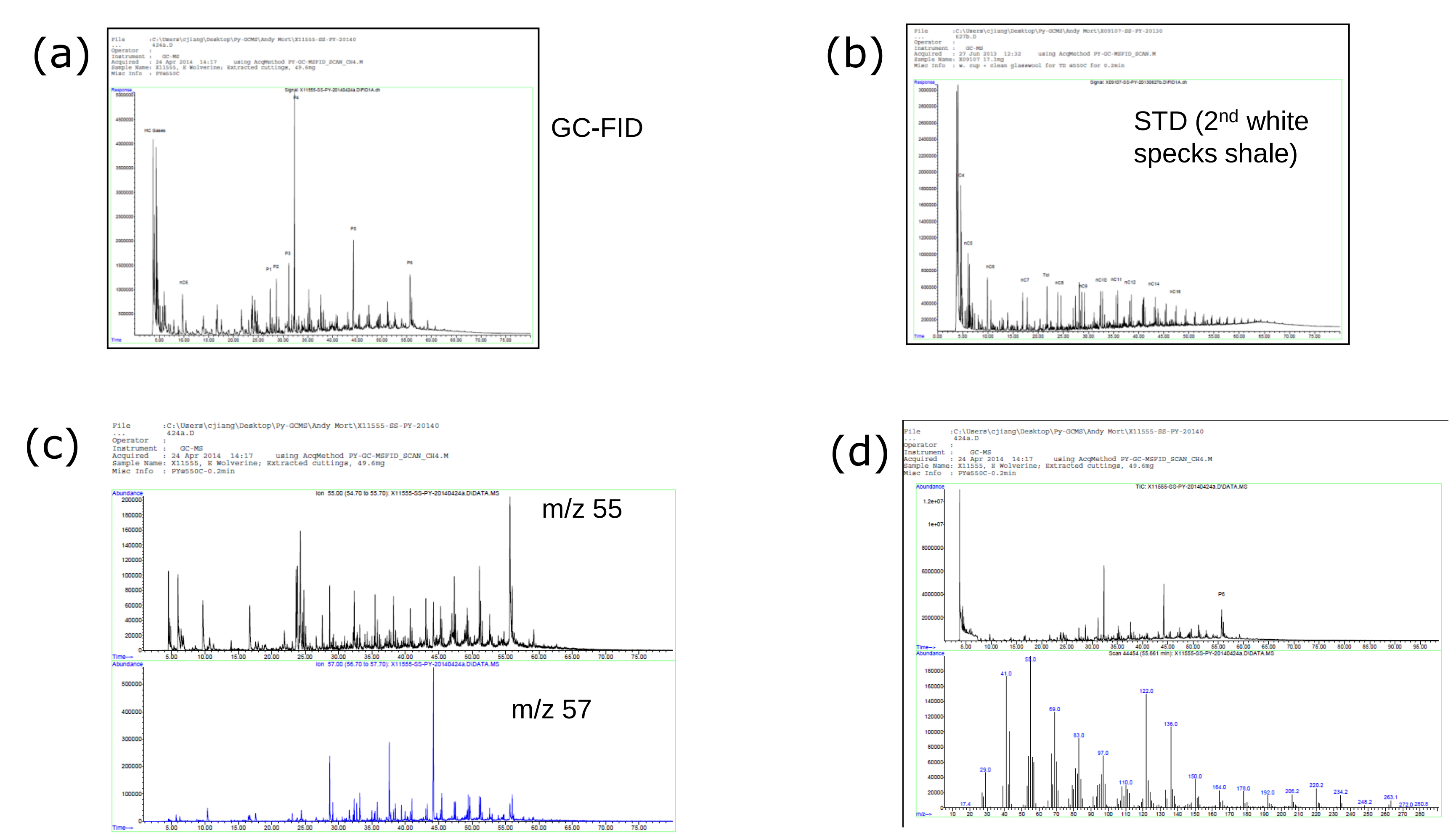
Attempts to remove contamination

Both GC (left) and Rock-Eval (above) results suggest levels of contamination are significant enough to invalidate meaningful interpretation of these data. The extracted cuttings samples were re-analysed by Rock-Eval pyrolysis which removed most of the anomalously high S1 peak responsible for suspiciously high PI values. Selected pyrograms of the washed cuttings (left) and washed + extracted cuttings (right) are shown below. Note the reduction in the S1 peak following removal of the extractable hydrocarbon fraction.



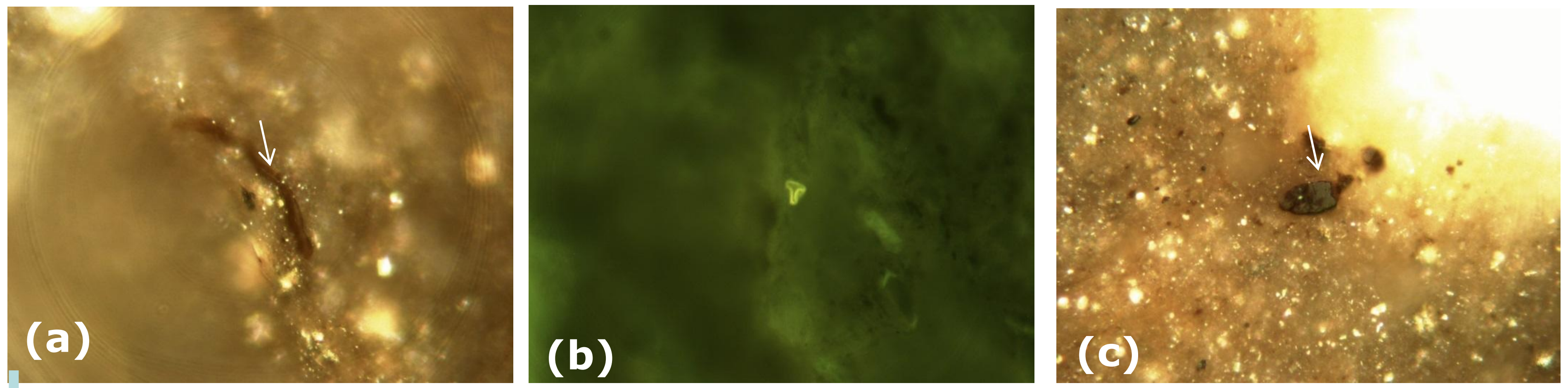
Analysis of residual insoluble organic matter by Pyrolysis GCMS

Further investigation of the Wolverine samples suggests that not only the S1 Rock-Eval peak is compromised but that the modern mud system used here has rendered the whole spectrum of geochemical screening results void, since the S2 peak appears to be composed of polymeric drilling additive rather than native organic matter. A sample of Second White Specks (Turonian organic rich shale) is shown for comparison and clearly displays homologous series of n-alkanes and alkenes as doublets which are notably absent from the GC-FID of the Wolverine cuttings sample. The lower figures show MS detection of the same sample demonstrating in (c) the predominance of alkenes and isoalkanes (m/z55) versus n-alkanes (m/z57) and in (d) the mass spectrum from one of the prominent peaks in the TIC suggesting a polymeric additive with regular methyl group fragmentation.



East Wolverine G-37 Organic Petrography

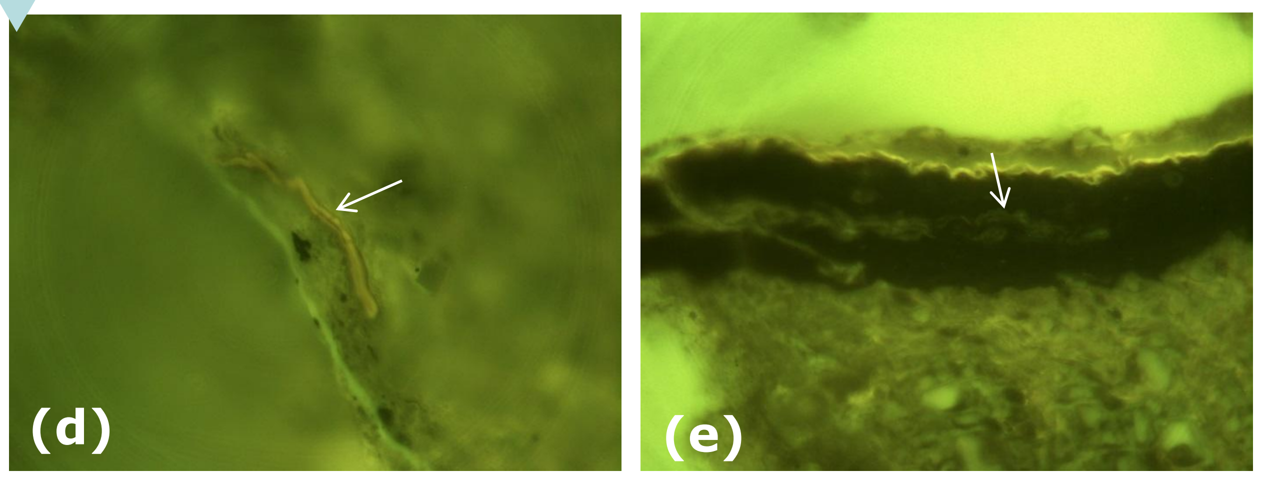
3585 m



(a) Sporinite maceral in white and fluorescence light (267-14)

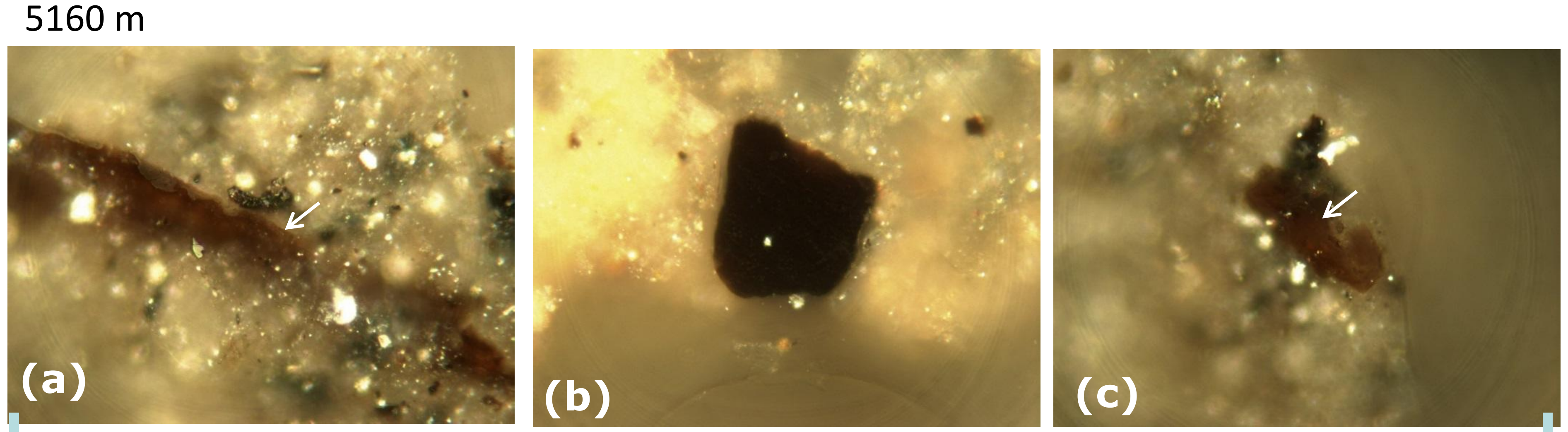
(b) Fluorescing sporinite maceral and vitrinite maceral (polish section) (267-14)

(c) Vitrinite (arrow) (267-14)



(e) Sporinite (fluorescing in the center) filled sporangium (267-14)

5160 m



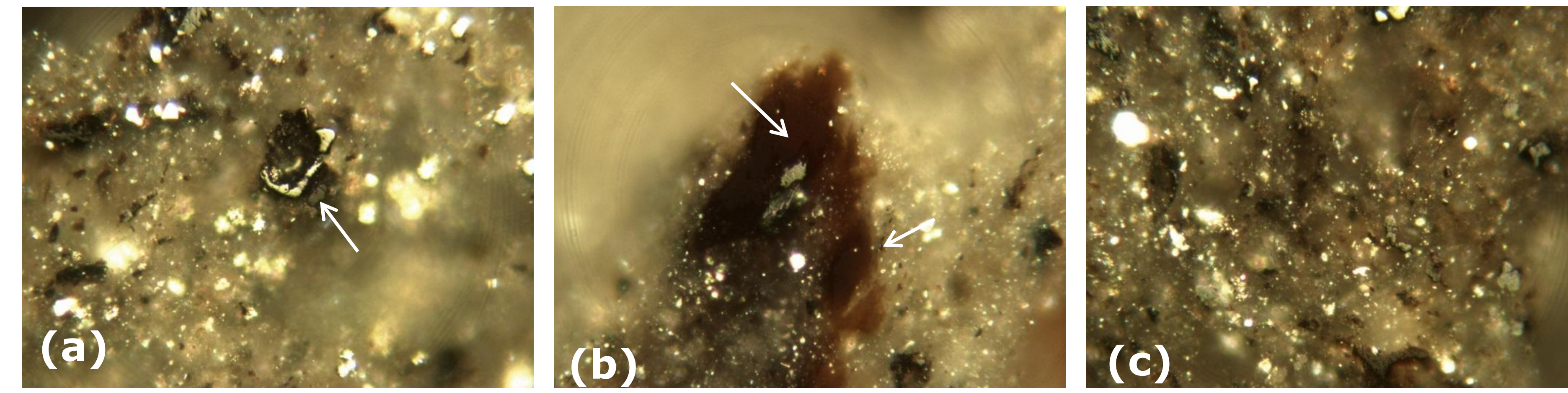
(a) Cutinite in white and fluorescence light (271-14)

(b) Organic contaminant (271-14)

(c) Sporinite in white and fluorescence light (271-14)

(e) Vitrinite maceral (271-14)

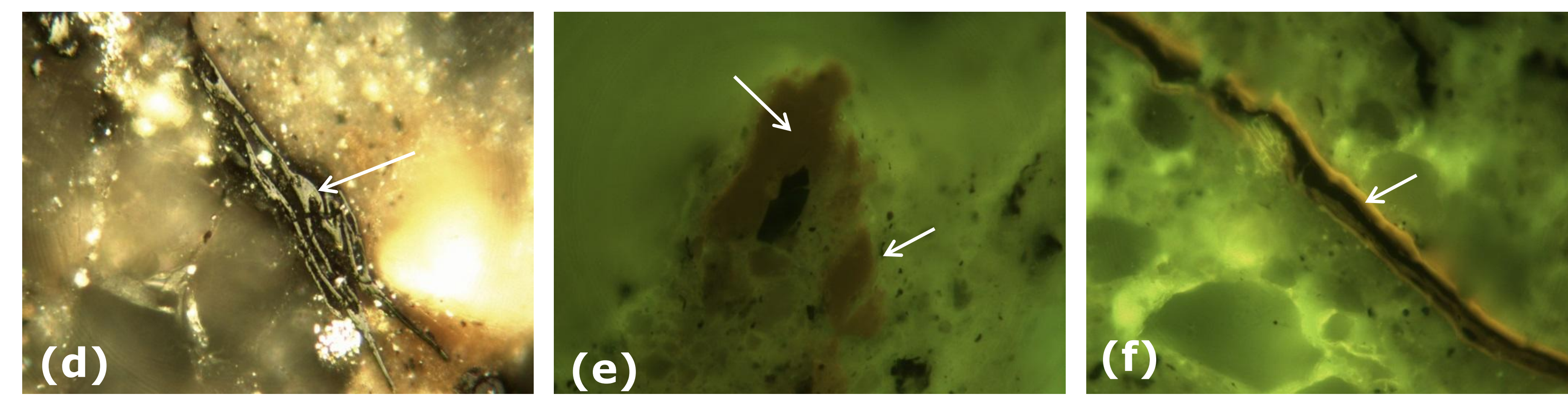
5160 m



(a) Vitrinite (arrow) (270-14)

(b) Bitumen under white and fluorescence light (270-14)

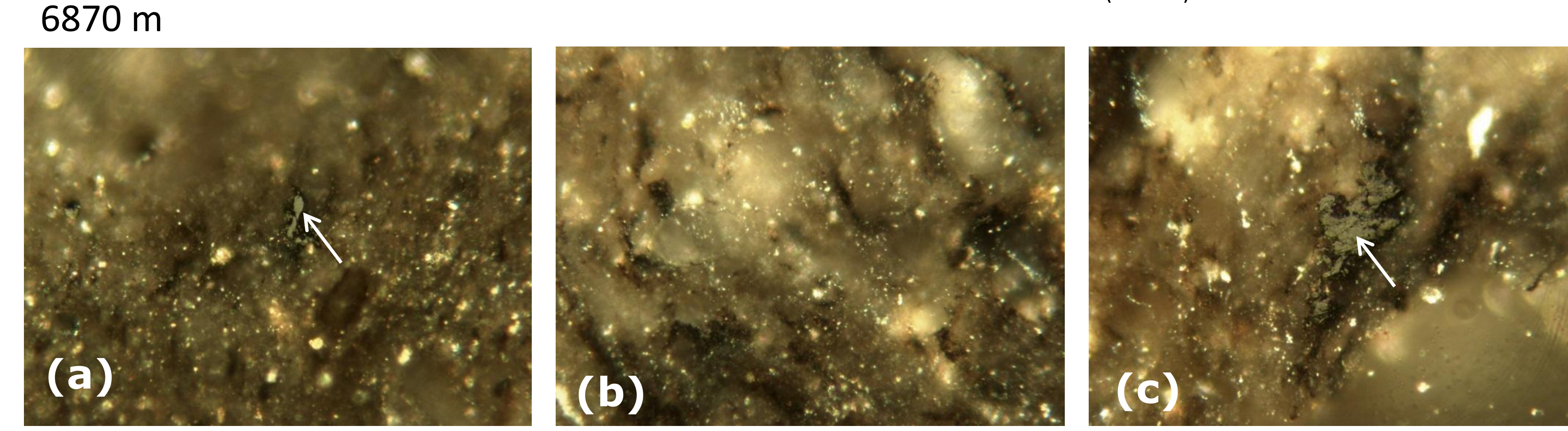
(c) Representative view of various organic macerals (270-14)



(d) Inertinite (arrow) 270-14

(f) Cutinite in luorescence light, possibly from root (271-14)

6870 m



(a) Vitrinite (arrow) (266-14)

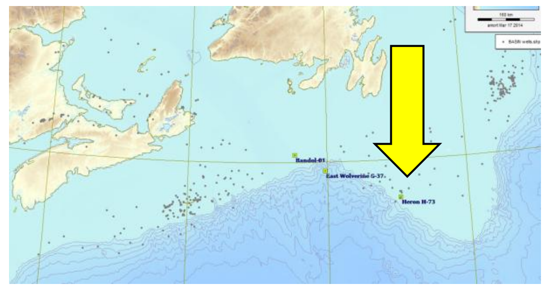
(b) Representative view of various organic macerals and mineral composition (266-14)

(c) Micrinite filled granular gelinite maceral (266-14)

The cuttings recovered from East Wolverine were also prepared for Organic Petrologic analysis with considerable difficulty due to contamination from drilling mud system components. Much of the visible organic matter is terrestrial in origin and a significant percentage is reworked. The centre top image of a well preserved sporinite maceral fluorescing under UV light is a notable exception to this (3585 (b))

Sufficient vitrinite is present to allow reflectance measurement and obtain a reasonable maturity profile . Some bitumen staining is evident (5160(b)) but based on the well reports which record no oil shows, this is not likely to be significant with respect to hydrocarbon generation.

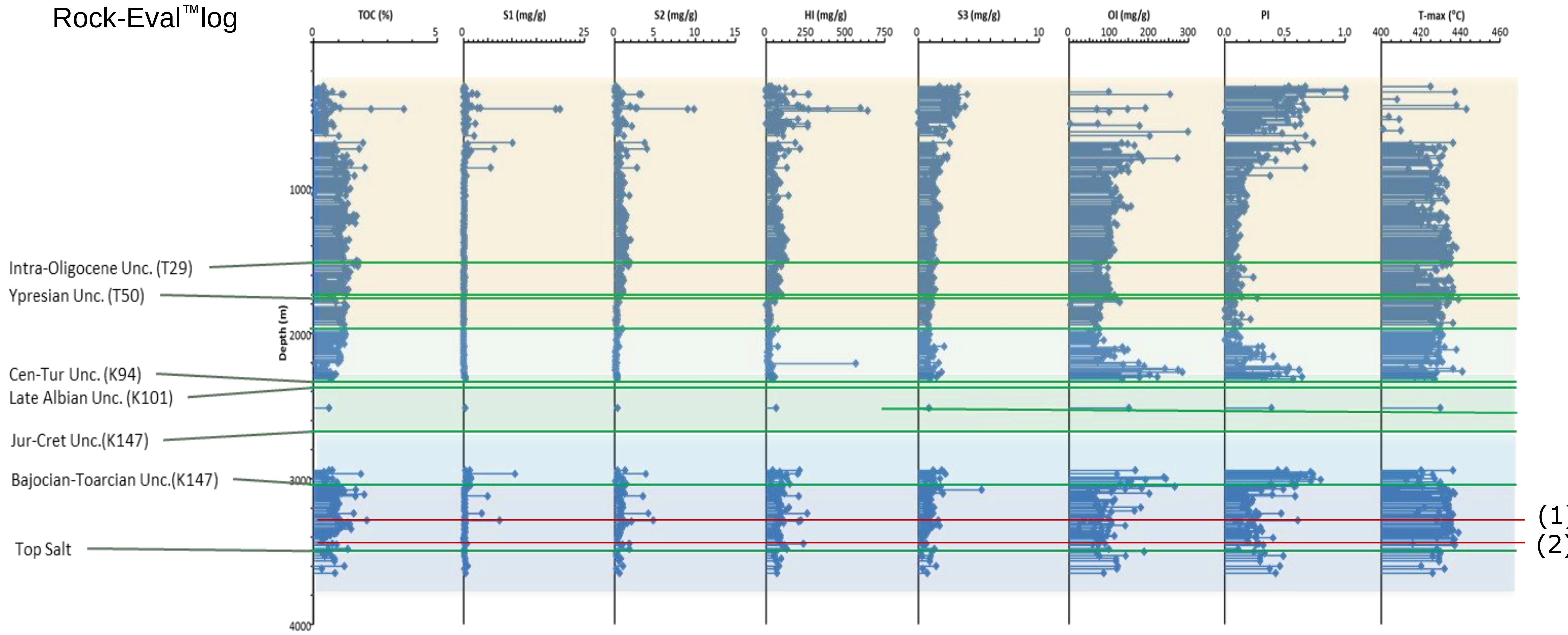
In addition to the various indigenous organic macerals, most of which are terrestrial in origin image 5160 (b) shows a fragment of solid organic contaminant potentially representing the material analysed in the Rock-Eval S2 peak and subsequently characterised by pyrolysis GCMS.



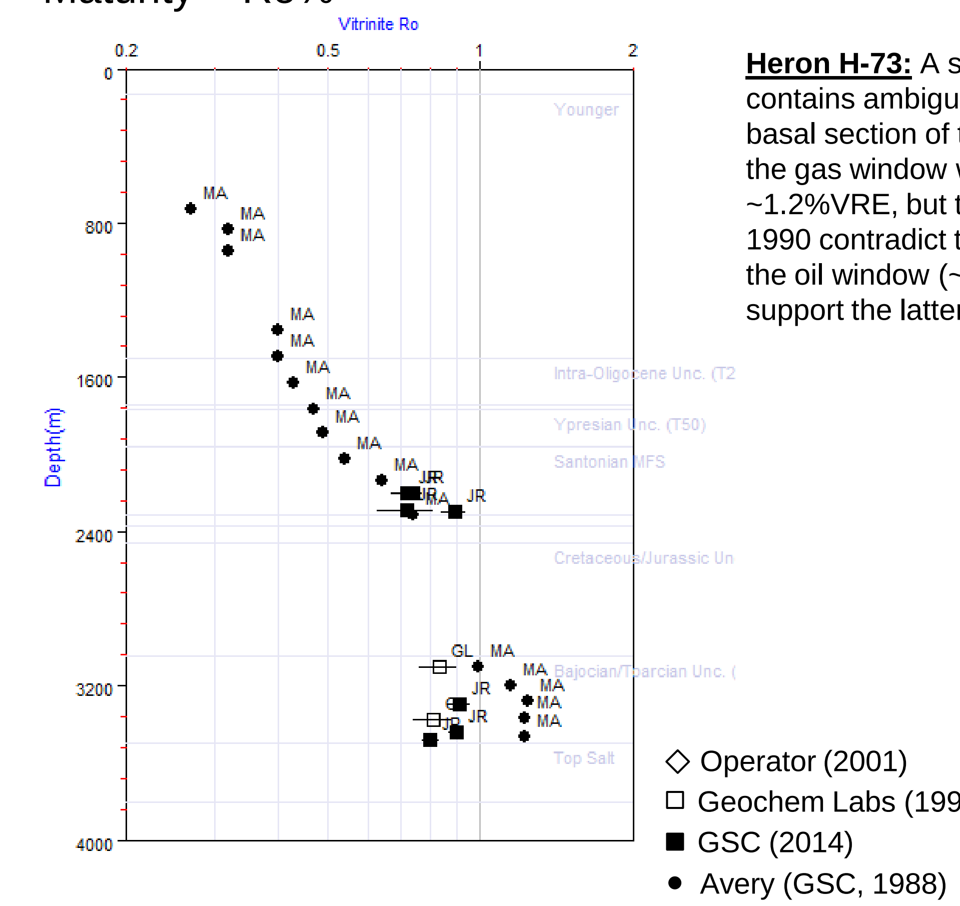
Heron H-73 Rock-Eval™

Source rock screening data from Heron H-73, drilled in 1972, is also somewhat compromised by oil based mud. Noting the scale on the TOC plot (0-5%) it is apparent that the penetrated sections of this well do not represent excellent source rock potential.

Rock-Eval™log

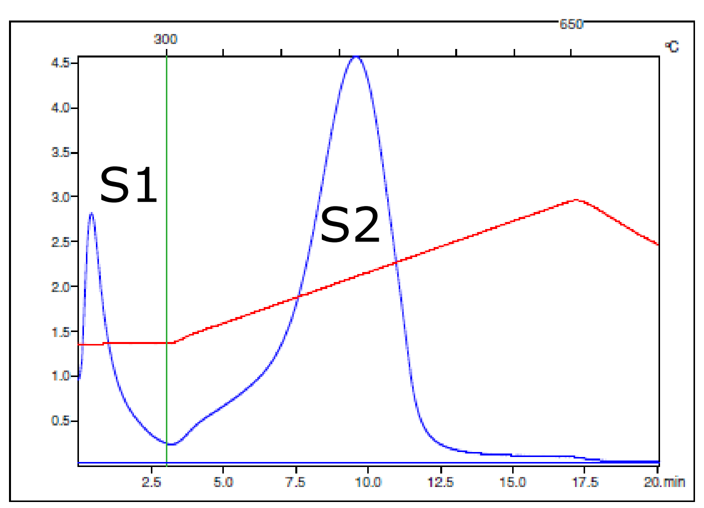


Maturity – Ro%



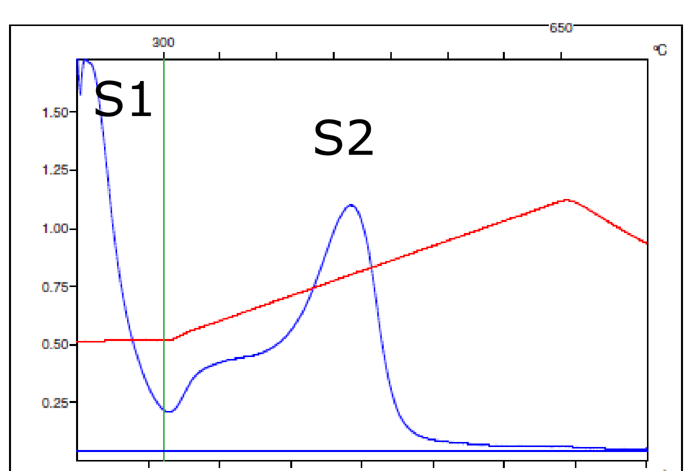
Heron H-73: A significant amount of existing data nonetheless contains ambiguous results for the key Jurassic interval in the basal section of the well. Avery (1988) suggests that this is in the gas window with values for the Early-Middle Jurassic of ~1.2%VRE, but two data points reported by Geochem Labs in 1990 contradict this, with maturity equivalent to the middle of the oil window (~0.8%VR_o). New results produced at the GSC support the latter conclusion.

Rock-Eval™ pyrograms



3291m (Toarcian mfs)

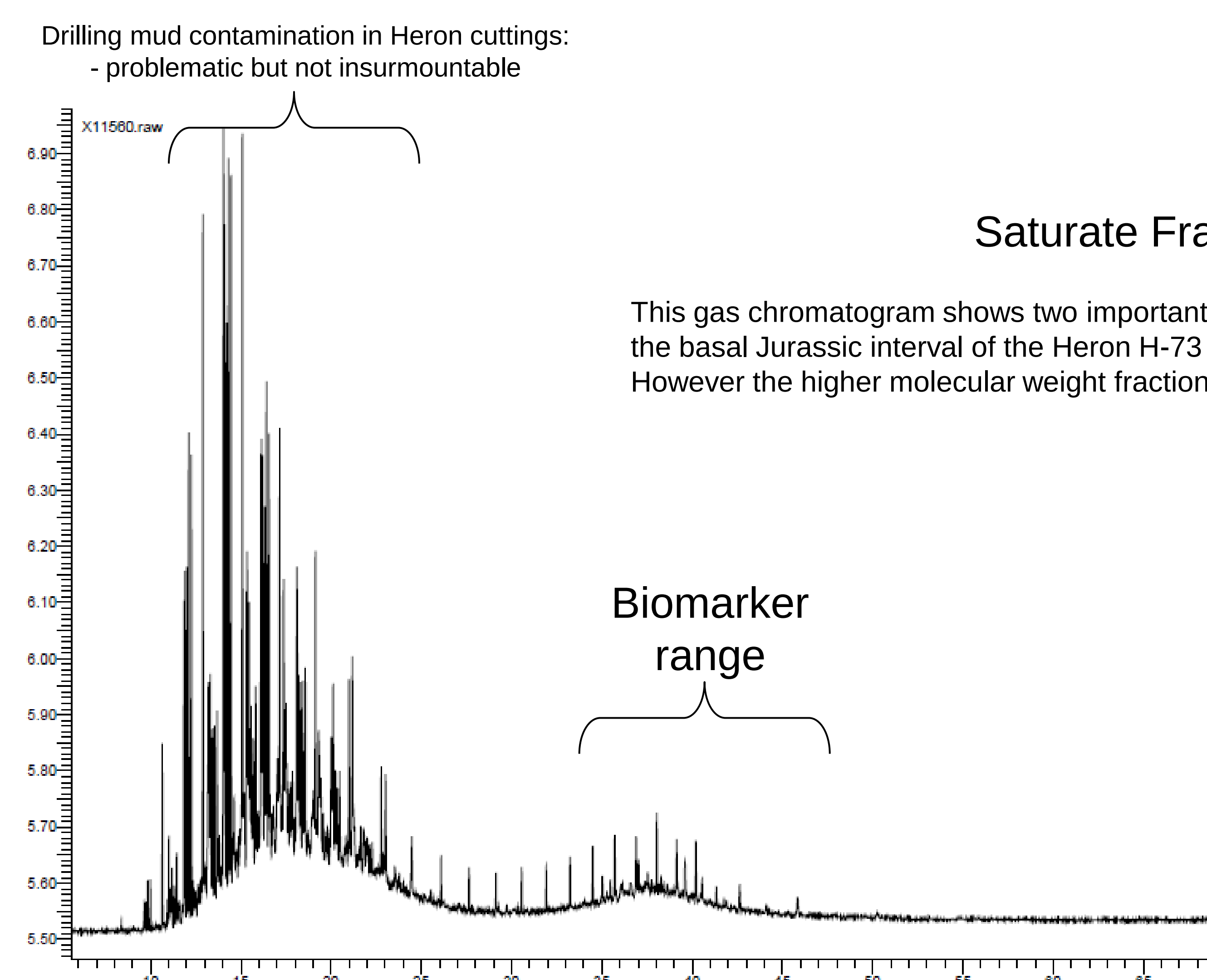
Sample #1 on geochemical log above



3444m (Pliensbachian mfs)

Sample #2 on geochemical log above

Gas Chromatography



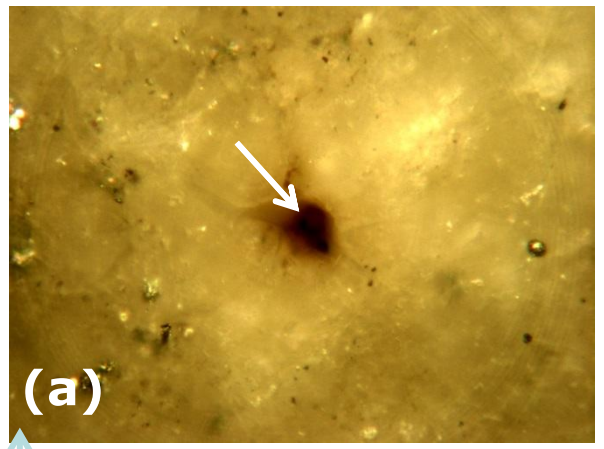
Saturate Fraction Gas Chromatogram

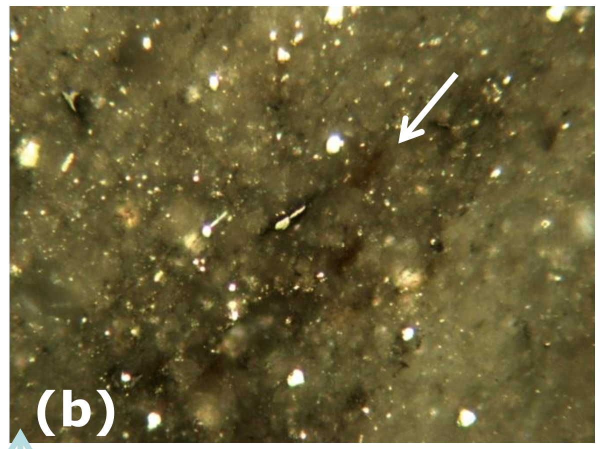
This gas chromatogram shows two important aspects of the extractable hydrocarbons seen in cuttings extracts from the basal Jurassic interval of the Heron H-73 well. The light hydrocarbon contamination is evident in the C10-15 range. However the higher molecular weight fraction appears relatively unaffected by OBM.

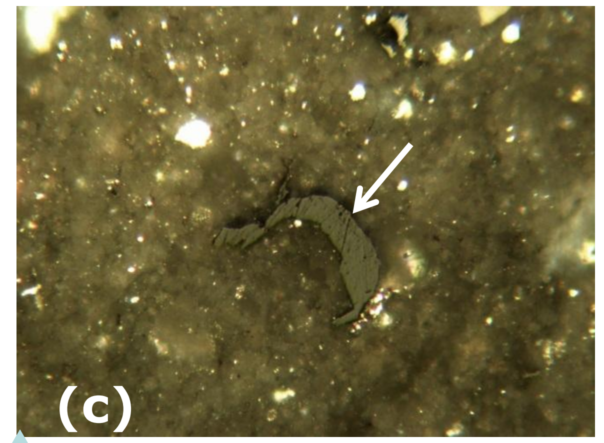
Heron H-73 Organic Petrography™

The presence of hydrocarbons in the Jurassic section of the Heron well is visually confirmed by organic petrographic observations detrailed here

3444.24 m (Pliensbachian)



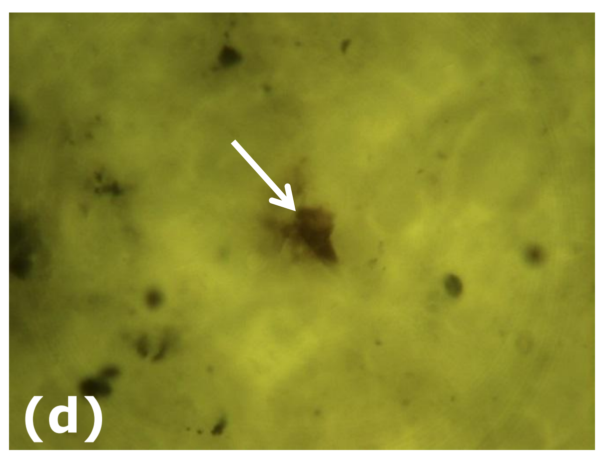


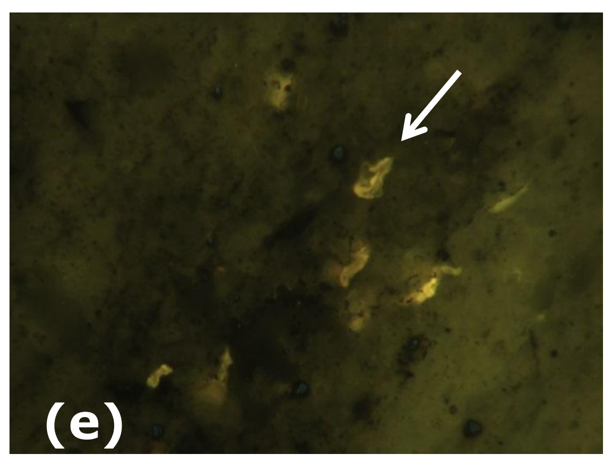


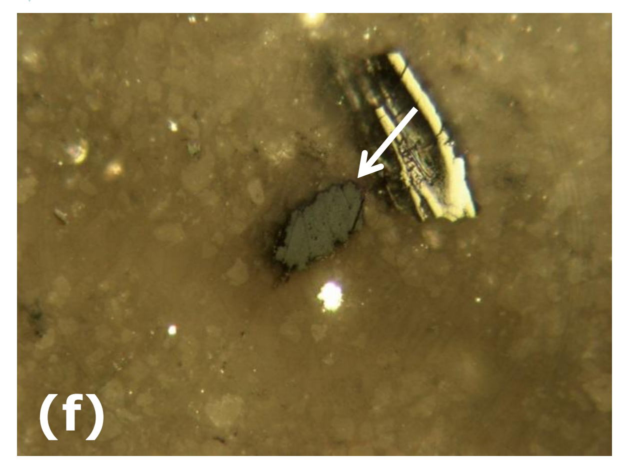
Fluorescing solid bitumen in pore

Fluorescing alginite maceral in white and UV light (arrow)

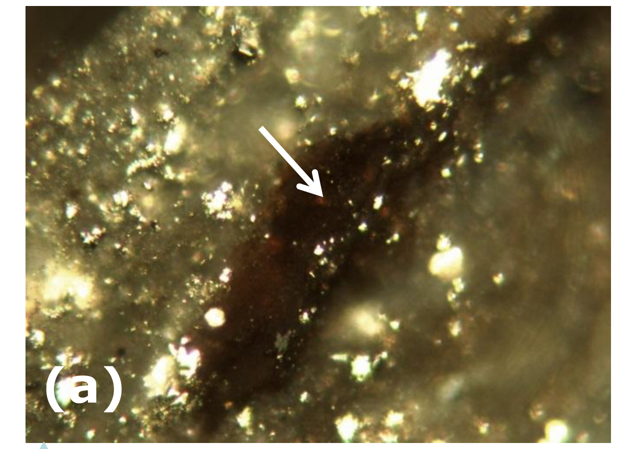
Non-fluorescing solid bitumen (arrow)

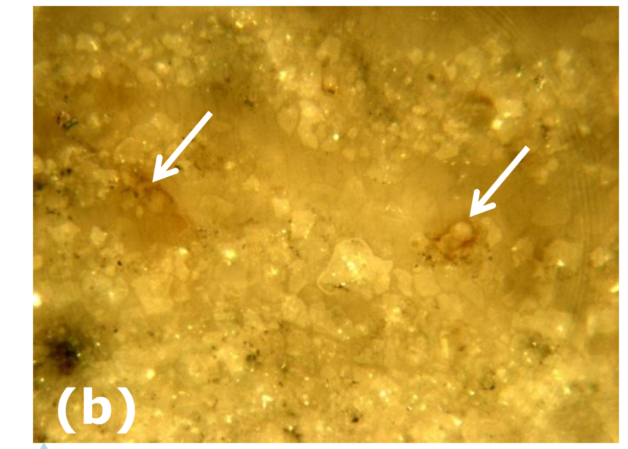


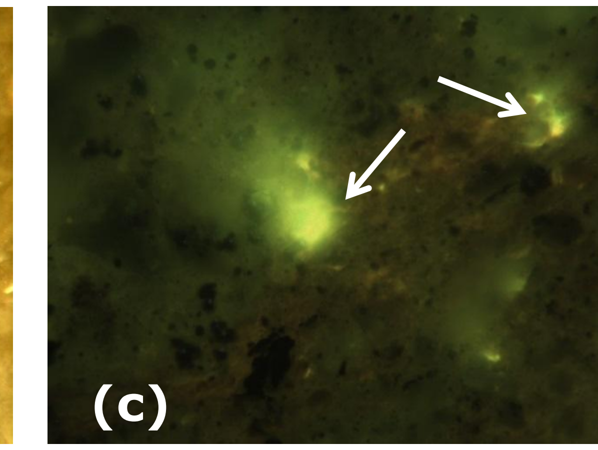




3444.24 m (Pliensbachian)



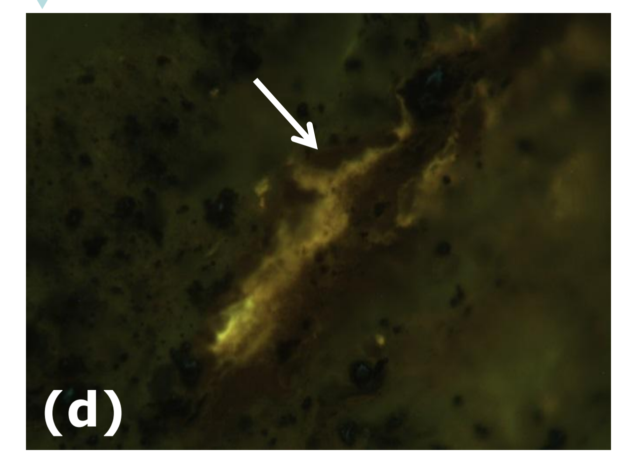


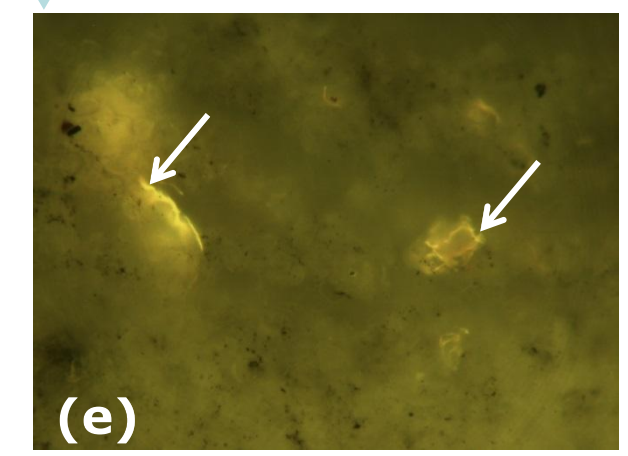


Fluorescing liptinite maceral (possibly matrix bitumenite) in pore.

Fluorescing alginite (left) and solid bitumen macerals in white and UV light (arrow)

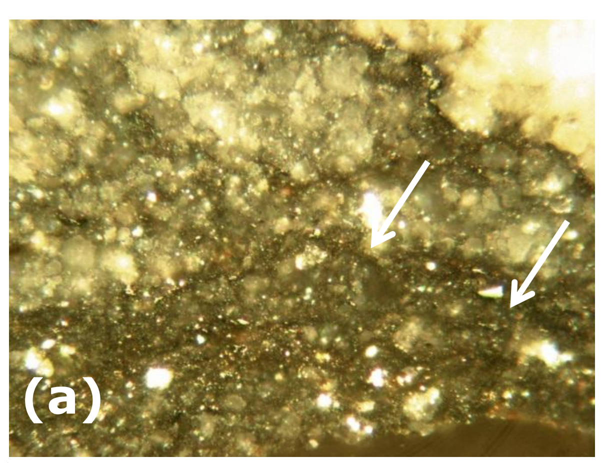
Bright yellow fluorescing soluble organic in UV light (arrow)

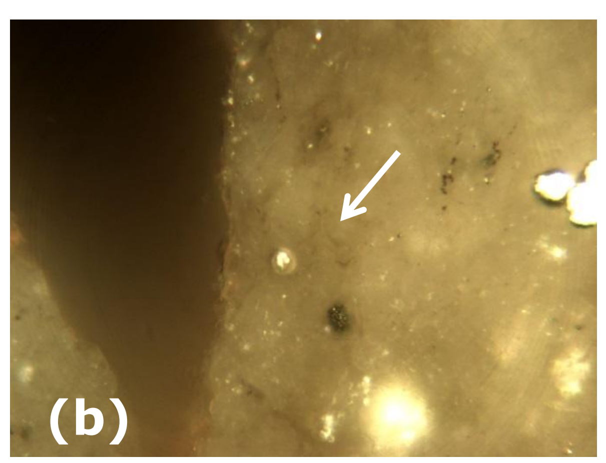


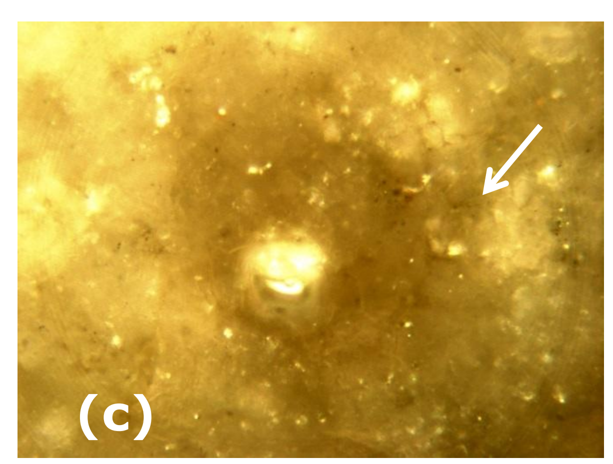


Staining does not occur outside each particle but as an inclusion within intergranular pores with some annealed inside a grain. As the oil migrates they leave brown stains between grains and fractures that may or may not fluorese depending on the thermal maturity.

3480.82 m (Pliensbachian-Sinemurian?)



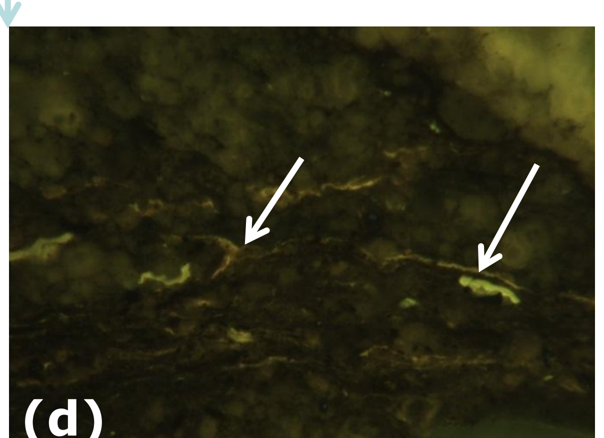


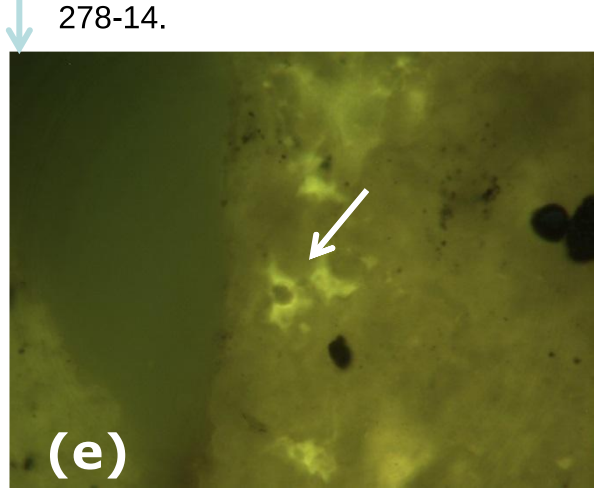


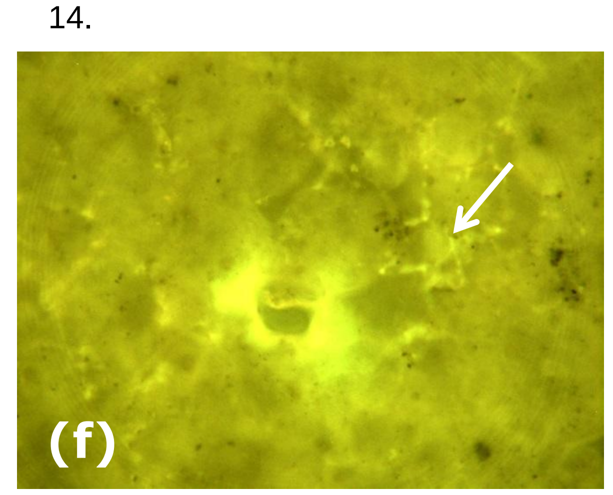
Fluorescing alginite maceral.

Fluorescing soluble organics (bitumen) in pores in white and UV light (arrow). Also observed in 278-14.

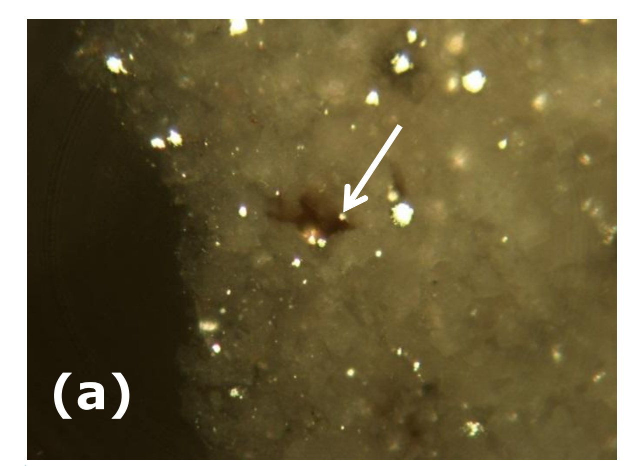
Fluorescing soluble organics (bitumen) in pores in white and UV light (arrow). Also observed in 278-14.

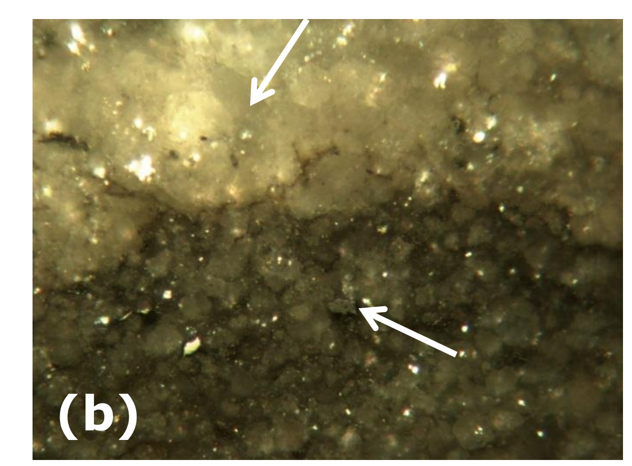






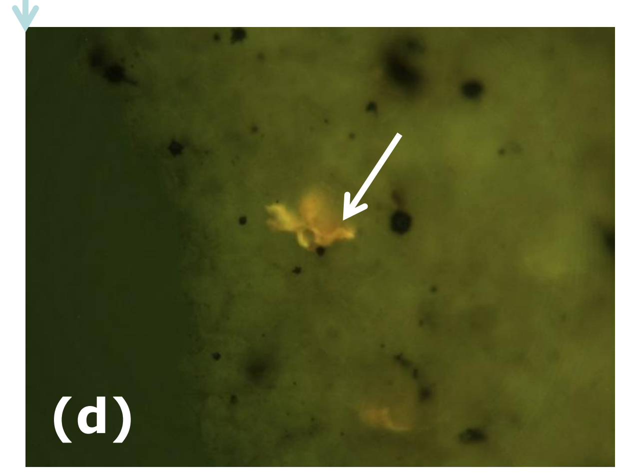
3480.82 m (Pliensbachian-Sinemurian?)



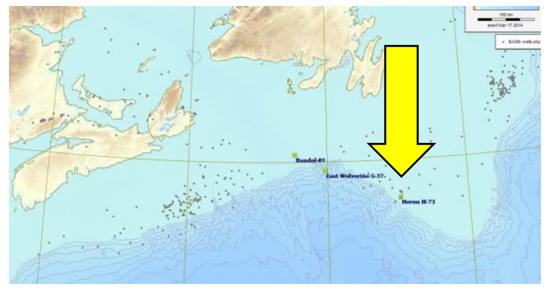


Fluorescing alginite maceral.

Organically lean dolomitic limestone (upper arrow). Solid bitumen in organic rich shaley calcareous limestone microlithoptypes (lower arrow).



The presence of soluble organics in pores and in fractures appears to be in-situ and not contamination. The fluorescence color indicates that these soluble organics are also about the same thermal maturity (0.80 to 0.95 %Ro) as the measured section. All fluorescing organic matter suggests that maturity is less 1.0 %Ro. One possible source of the hydrocarbons is the organic-rich shaley calcareous limestone

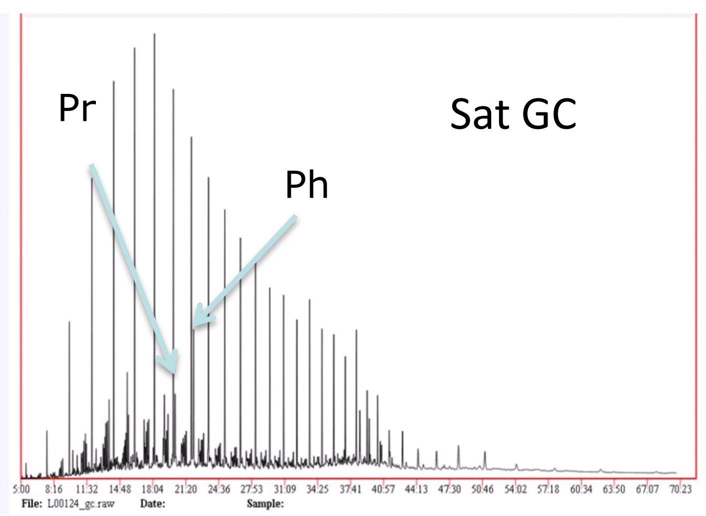


Heron H-73 DST#6 oil & Lower Jurassic extracts compared to regional oil families

Test Type	Stage	Surface Choke (mm)	Recovery	Comments
DST#06		25.4	22 BBLS HEAVY OIL (7-11.5 API)	
DST#06		25.4	102 BBLS SALT WATER	
DST#06		25.4		PACKER SKIDDED PAST PERFORATIONS
DST#06		25.4		PRESSURES MEASURED AT 7427 FEET
DST#06		25.4		TEMP 185 F (DEPTH N/A)
DST#06		25.4		

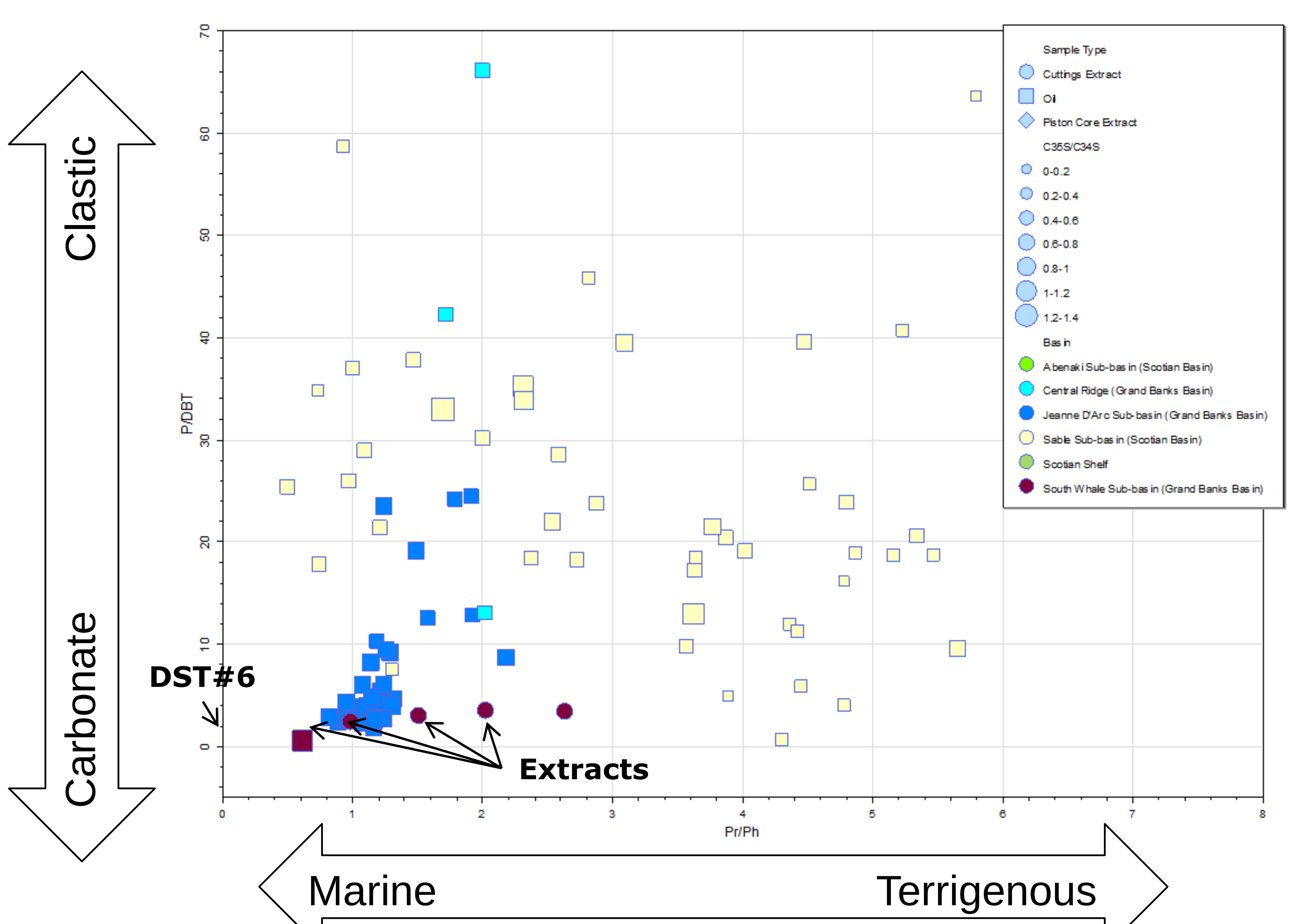
DST #6 recovered a heavy but remarkably unbiodegraded crude oil from the Petrel Limestone. Notable features are high C35 hopanes relative to C34 (m/z 191 ion chromatogram) indicating a sulfur-rich source, very low Pristane/Phytane ratio (anoxia) and very high C24 tetracyclic compared to the C26 tricyclic terpanes.

Gas Chromatography & bulk geochemistry

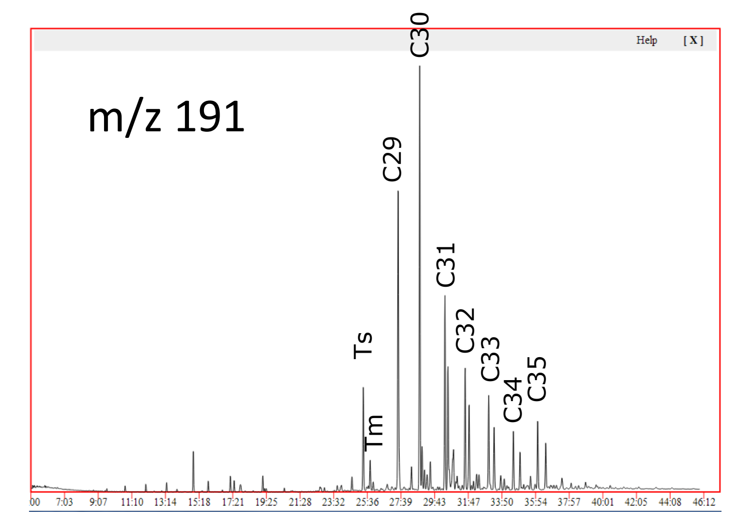


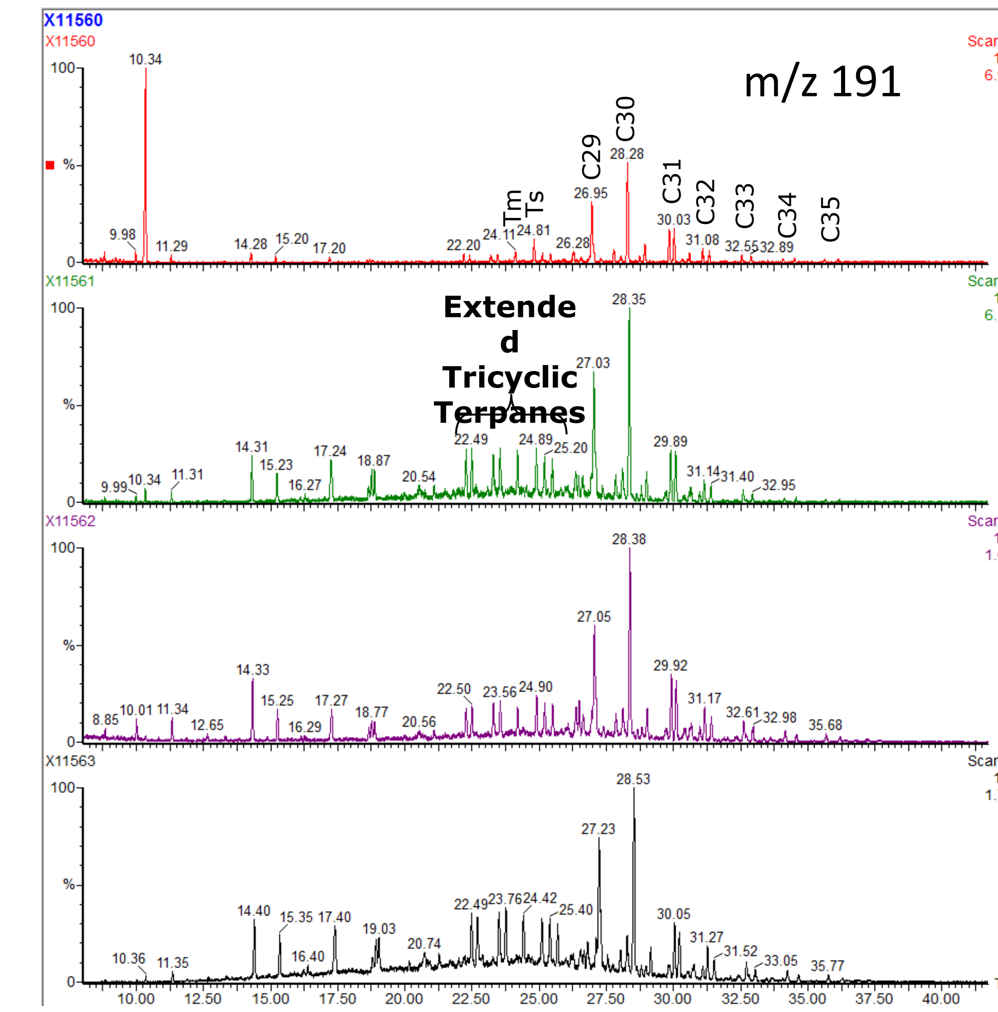
The Heron DST #6 oil has exceptionally high sulfur content and very low pristane/phytane ratio both of which point to a carbonate source deposited under highly reducing conditions. The GC shown above indicates no evidence of biodegradation even thought the oil viscosity is so high that it barely flows at room temperature (see photo above)

A plot of phenanthrene/dibenzothiophene versus pristane/phytane below demonstrates the separation of the Heron DST oil from all other regional oils due to its high sulfer content and low Pr/Ph value. Note that the Jurassic extracts from Heron H-73 are not associated with any of the other Scotian Shelf fluids



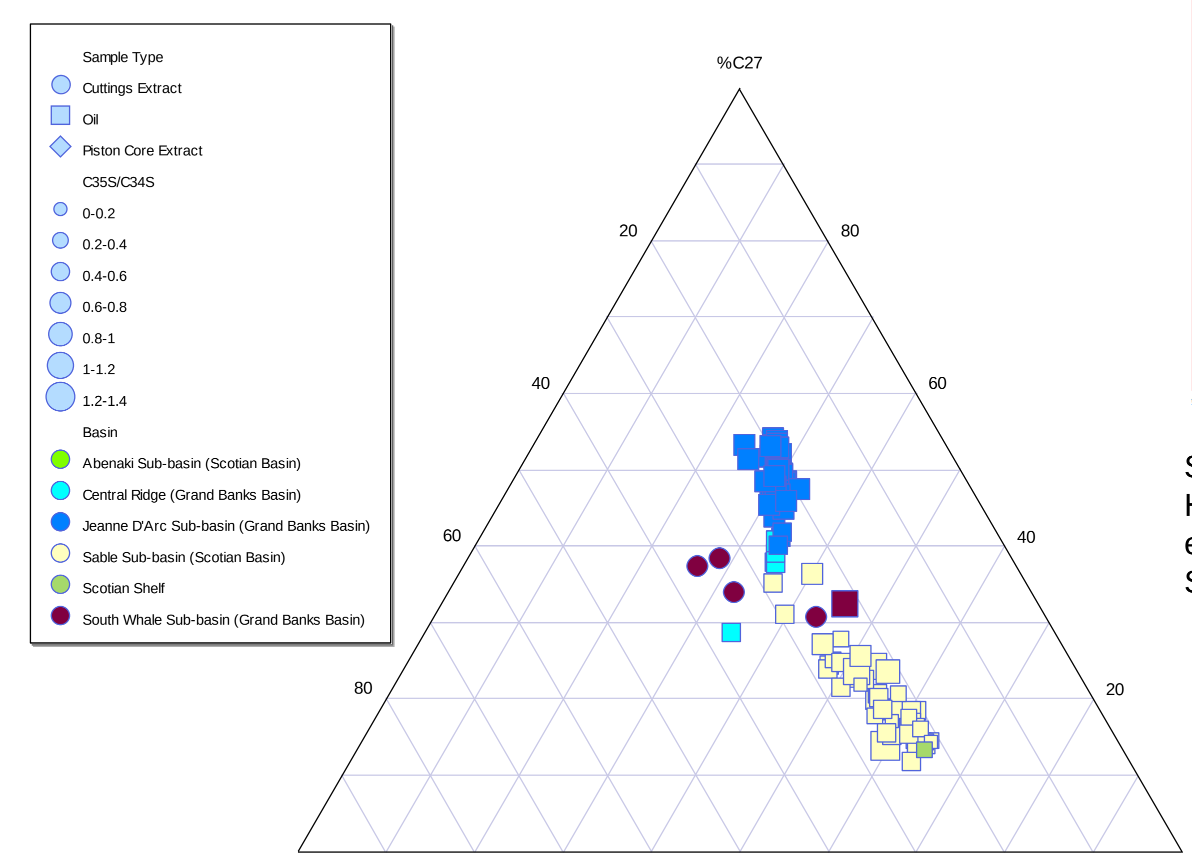
Terpanes (m/z 191)

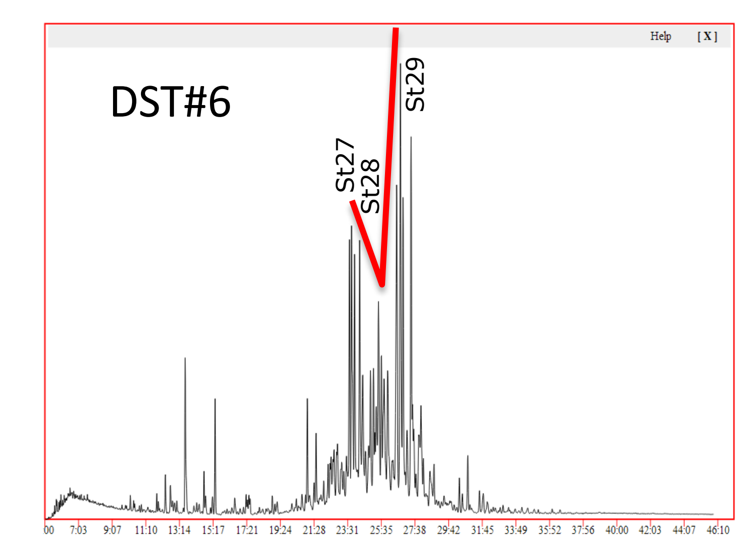




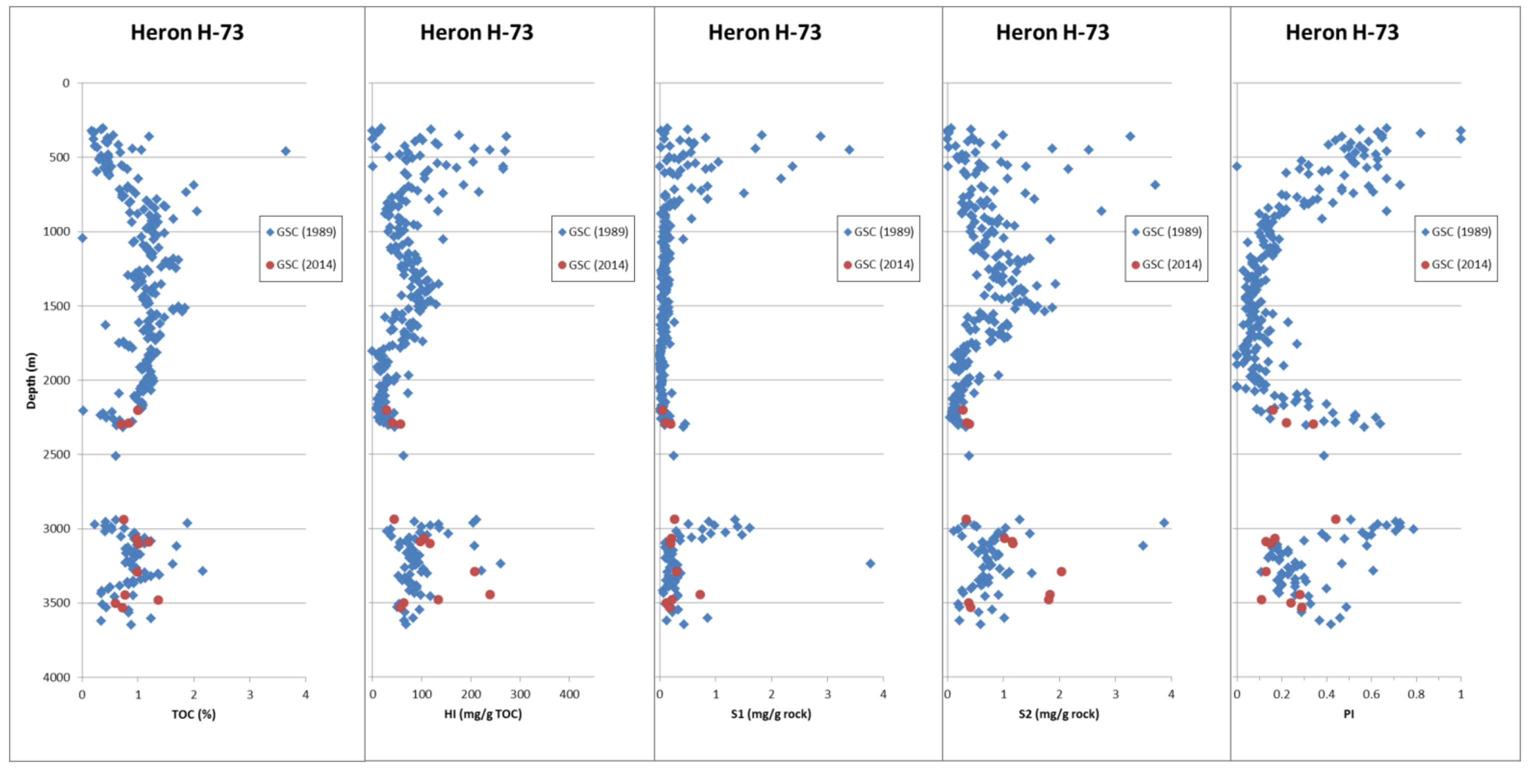
Hopane distributions in the DST oil (above) are indicative of a strongly reducing carbonate source rock, evidenced by high C35/34 extended hopanes, and very high C24 tetracyclic terpane relative to the C26 tricyclic terpane doublet.
These features are not evident in the Jurassic extracts from the deeper part of the Heron well (right), which are themselves highly distinctive due to the exceptionally prominent extended tricyclic terpanes. These have been previously suggested as diagnostic indicators of Triassic and Early Jurassic oils

Steranes(m/z 217)





Sterane carbon number distributions for both the Heron DST#6 oil (shown above) and Jurassic extracts are distinct from the vast majority of Scotian Shelf fluids.



In blue, legacy data from the GSC database.

In red, newly acquired data for this study

Figure 1: Plots of Rock Eval pyrolysis data for the Heron H-73 well. Tmax is displayed in Figure 2 (this Plate) along with Ro data.

Depth	Qty	S1	S2	PI	S2/S3	S3	Tmax	PC(%)	TOC(%)	HI	OI
2203.7	70.8	0.05	0.28	0.16	0.16	1.73	425	0.09	0.99	28	175
2286	70.3	0.1	0.34	0.22	0.20	1.7	424	0.1	0.84	40	202
2298.19	70.3	0.2	0.39	0.34	0.25	1.55	422	0.1	0.7	56	221
2938.27	70.6	0.26	0.33	0.44	0.26	1.25	420	0.1	0.75	44	167
3066.29	70.7	0.21	1.02	0.17	0.58	1.76	431	0.17	0.97	105	181
3087.62	70.8	0.18	1.15	0.13	0.91	1.26	433	0.16	1.19	97	106
3102.86	70.1	0.2	1.17	0.15	0.57	2.04	431	0.19	1.01	116	202
3291.84	70.3	0.3	2.03	0.13	1.95	1.04	432	0.23	0.98	207	106
3444.24	70.1	0.72	1.83	0.28	2.61	0.7	416	0.24	0.77	238	91
3480.81	71.1	0.22	1.81	0.11	1.34	1.35	428	0.23	1.36	133	99
3502.15	70.4	0.12	0.38	0.24	0.34	1.13	430	0.08	0.6	63	188
3529.58	70.5	0.17	0.41	0.29	0.40	1.02	426	0.08	0.72	57	142

Table 1: Newly acquired Rock Eval pyrolysis data (red dots in the plots above) for this study

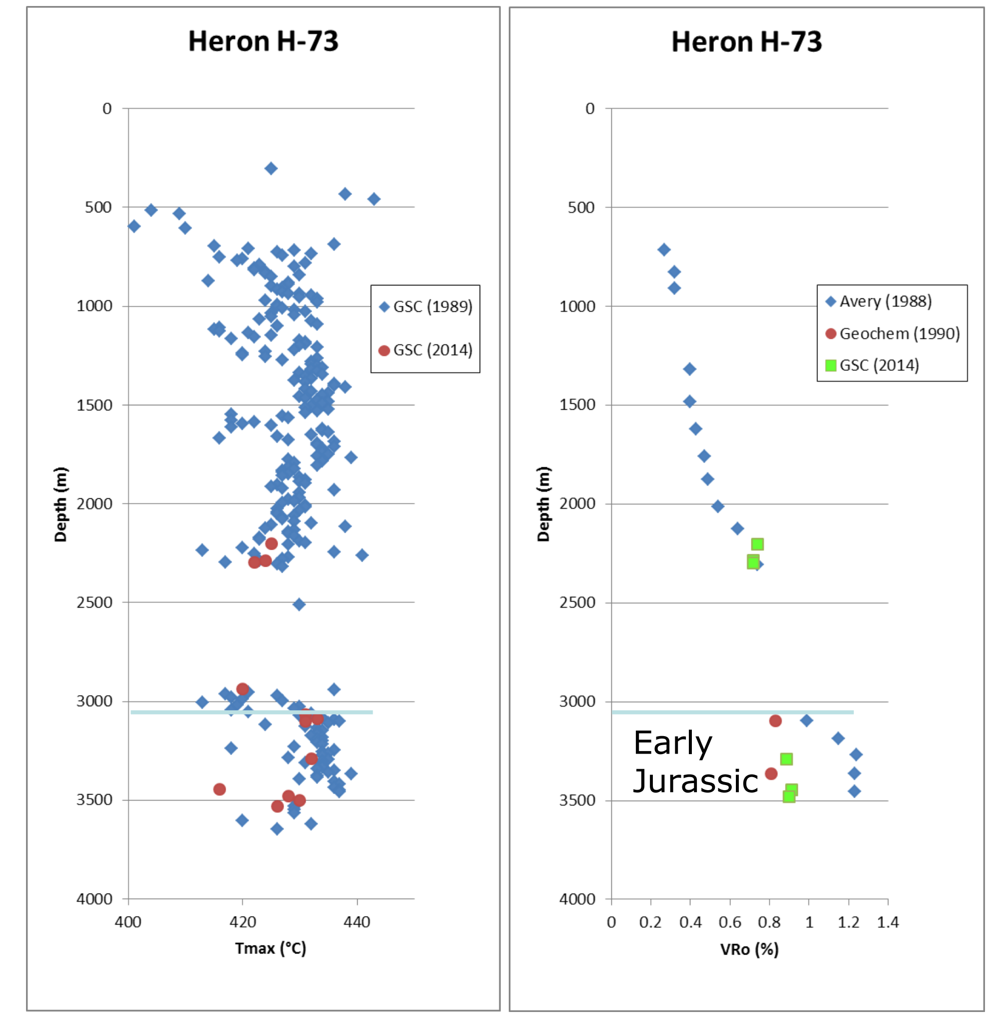
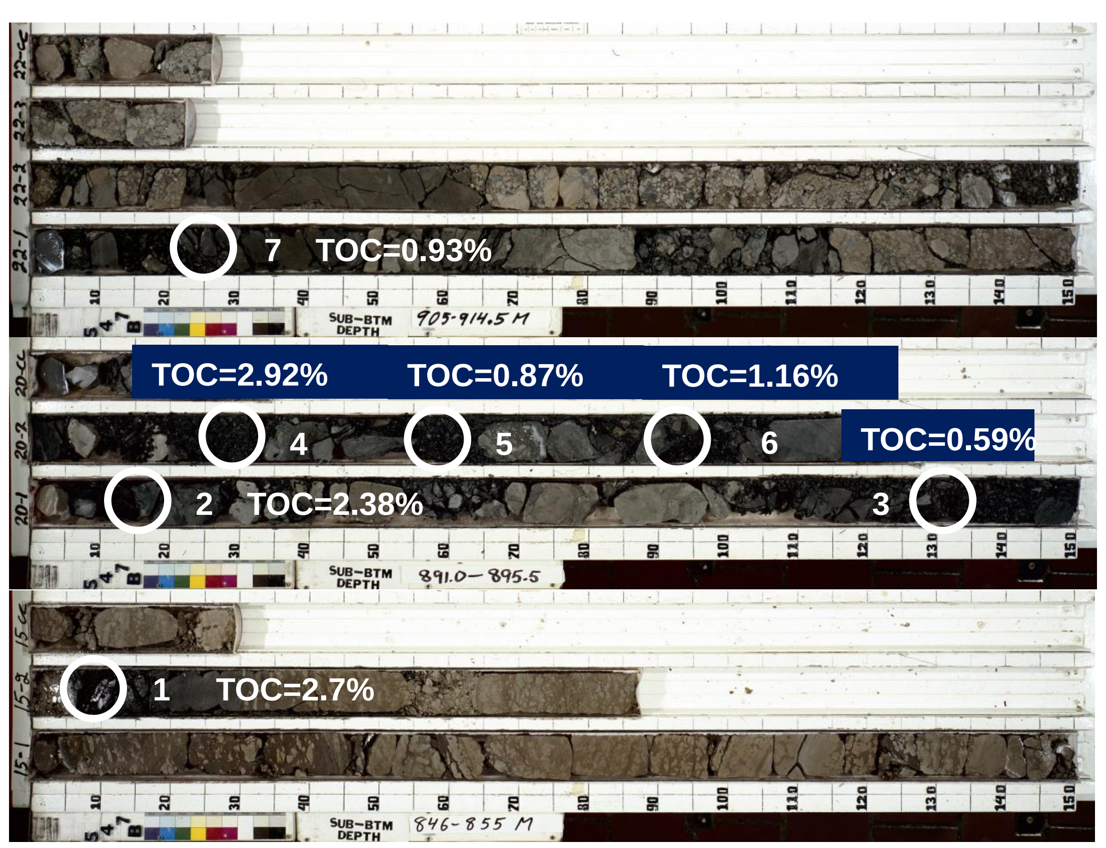


Figure 2: Vitrinite Reflectance and Tmax seem to agree on the maturity of the Early Jurassic part of the well. Above, the Tmax gradient is roughly vertical and therefore unreliable (mud contamination).



Depth	Sample	Qty	Tmax	S1	S2	S3	PI	S2/S3	PC(%)	TOC(%)	HI	OI
0	9107	70.7	442	0.74	12.21	0.55	0.06	22.20	1.11	5.05	242	11
847.55	4421954	70.0	423	0.10	4.04	2.87	0.02	1.41	0.47	2.70	150	106
891.11	4421955	70.9	423	0.13	8.82	1.94	0.01	4.55	0.82	2.38	371	82
892.3	4421956	70.3	423	0.03	0.25	1.56	0.10	0.16	0.08	0.59	42	264
892.79	4421957	70.6	425	0.10	6.31	1.71	0.02	3.69	0.61	2.92	216	59
893.01	4421958	70.1	425	0.04	0.63	1.80	0.05	0.35	0.12	0.87	72	207
893.39	4421959	70.3	491	0.00	0.01	1.78	0.21	0.01	0.07	1.16	1	153
905.2	4421960	70.6	425	0.05	0.53	1.61	0.08	0.33	0.11	0.93	57	173
0	9107	70.4	442	0.72	12.18	0.63	0.06	19.33	1.11	5.09	239	12

Table 2: TOC/Rock Eval data acquired on the cores samples collected from DSDP well 547B. (Yellow outline: TOC/Rock Eval standard; Red outline: source rock samples analyzed for Biomarkers.

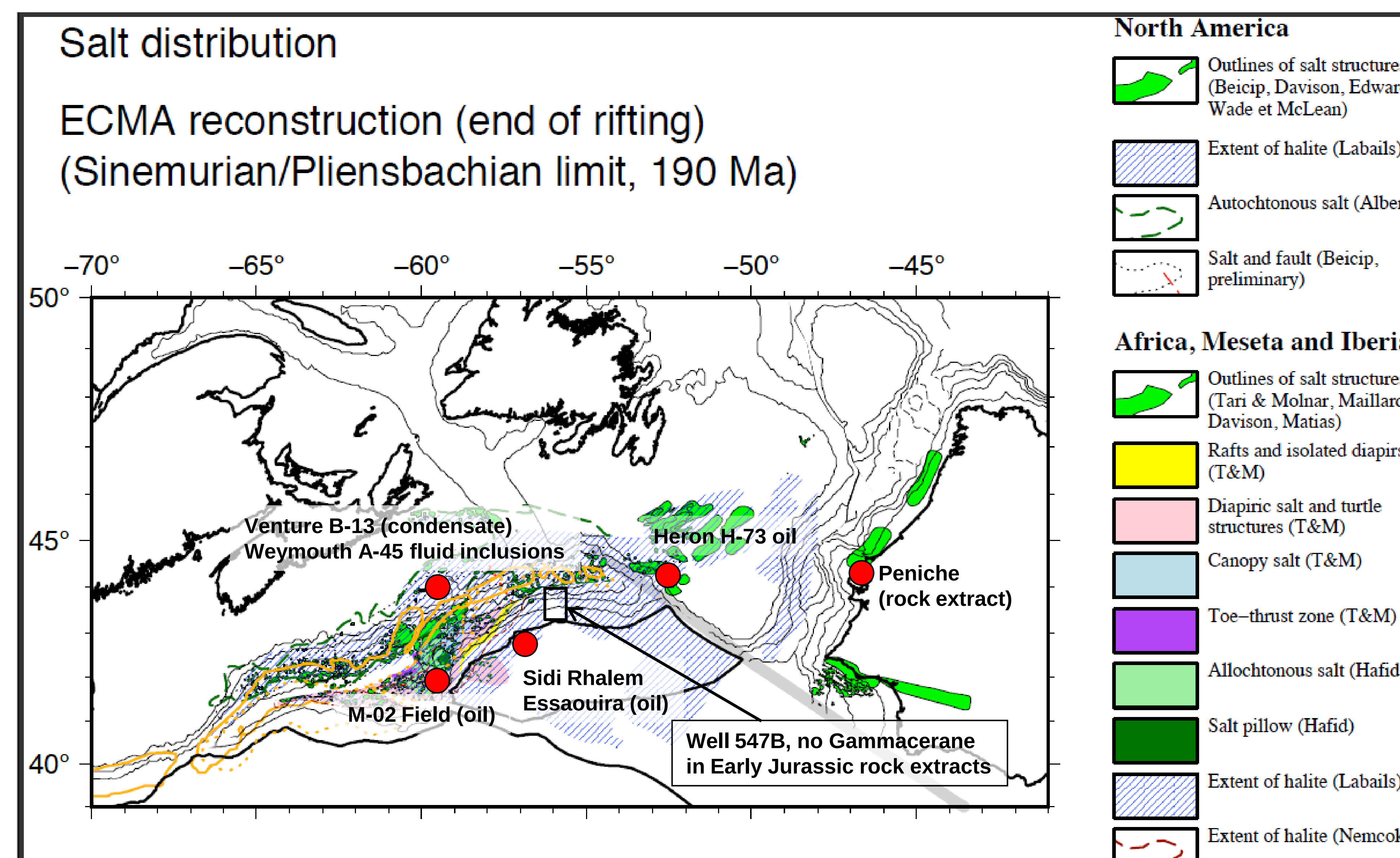


Figure 3: Rift reconstruction 190 Ma and salt distribution by Sibuet (2010). Red dots show locations of Gammacerane occurrences in oils, condensates, rock extracts and hydrocarbon fluid inclusions. Gammacerane is absent or in very low abundance in Early Jurassic organic-rich intervals of DSDP wells 547B and Heron H-73. Also, there is no salt deposited in the Triassic/Jurassic interval of well 547B.

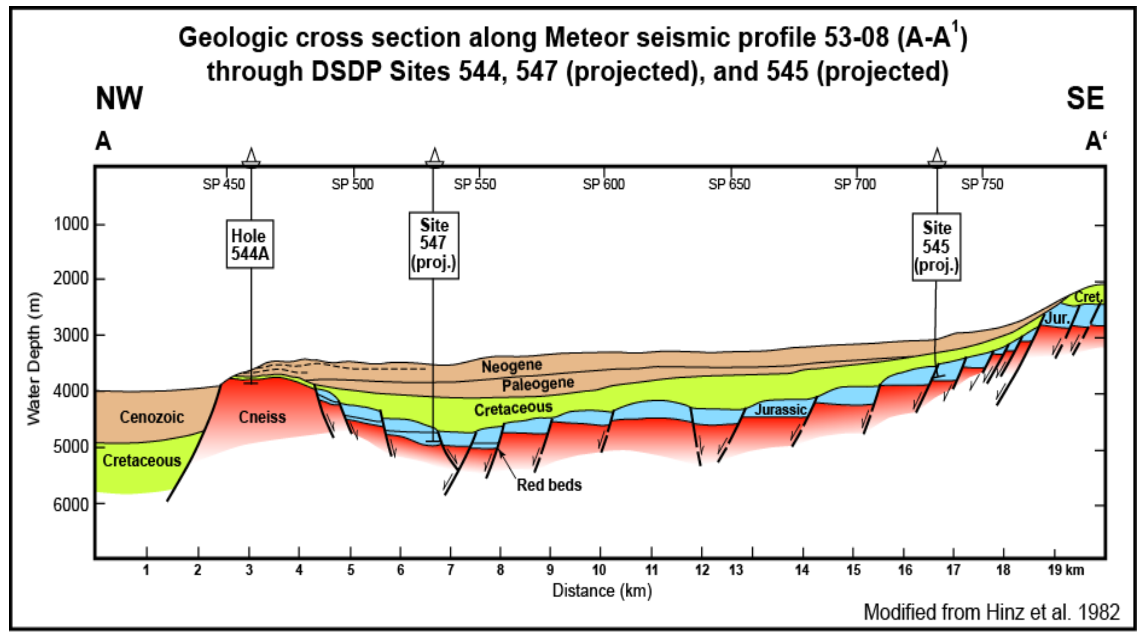


Figure 1: Cross section showing well locations of DSDP Leg 79, Sites 544, 545 and 547

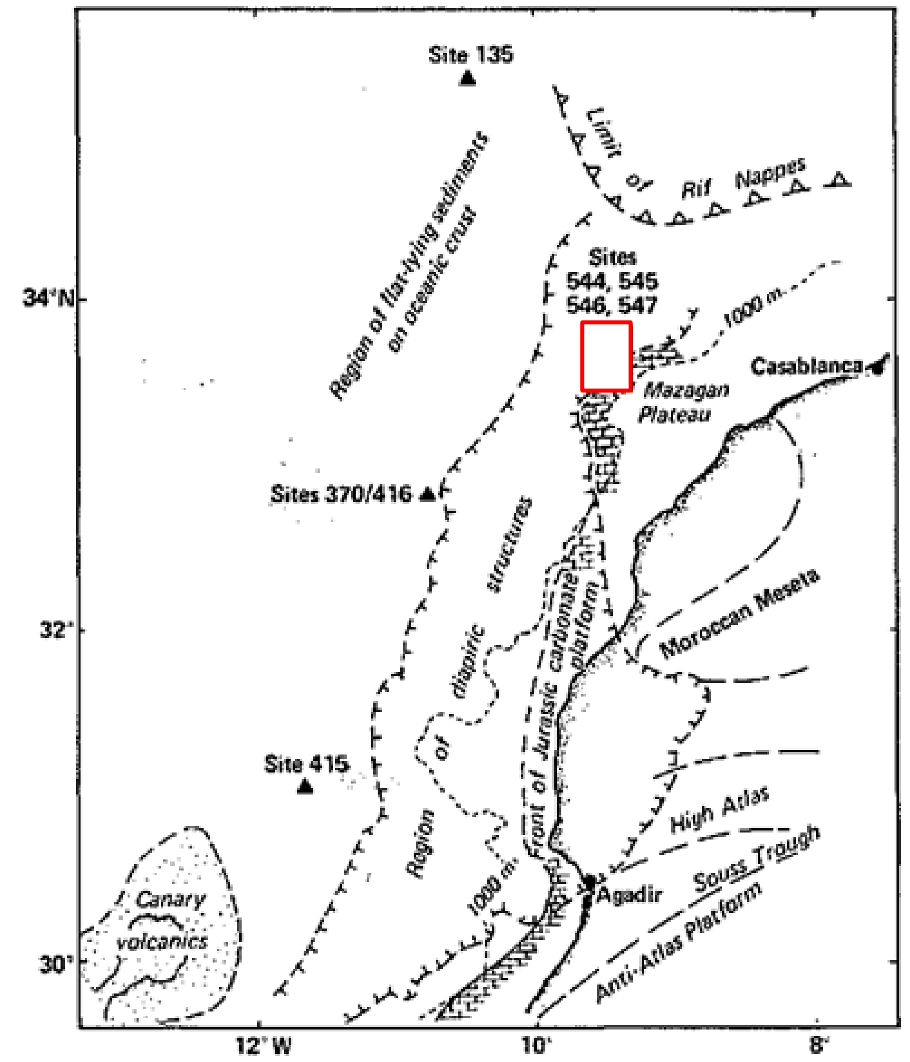


Figure 2: Location of DSDP drill sites Leg 79, Site 547 (within the red rectangle) on the Morocco margin (modified from Rullkötter et al. (1984).

Sample (interval in cm)	Depth (m)	Facies type[a]	C_{org} (%)	Rock-Eval pyrolysis: HI (mg hc/g C_{org})	Rock-Eval pyrolysis: OI (mg CO_2/g C_{org})	Rock-Eval pyrolysis: T_{max} (°C)	Extract (mg/g C_{org})	Liquid chromatography: Nonaromatic hydrocarbons (%)	Liquid chromatography: Aromatic hydrocarbons (%)	Liquid chromatography: Hetero-compounds (%)
547B-14-2, 56–58	839.07	C	0.39	19	122	434	—	—	—	—
547B-15-2, 2–5	847.54	Nodular micrite and claystone	0.30	12	269	426/534	—	—	—	—
547B-15-2, 8–12	847.60	A	4.75	345	15	421	10	16	12	72
547B-15-2, 14–17	847.66	A	1.13	49	87	421	13	23	13	64
547B-15-2, 20–26	847.73	Nodular micrite and claystone	0.69	18	142	422	11	32	11	57
547B-15-2, 39–41	847.90	Nodular micrite and claystone	0.28	7	377	427/534	—	—	—	—
547B-16-1, 29–42	855.36	Nodular micrite and claystone	0.10	8	302	424/524	—	—	—	—
547B-18-1, 100–117	874.09	A	0.70	18	137	425	5	18	5	77
547B-20-1, 134–140	892.37	Nodular micrite and claystone	0.92	71	113	424	—	—	—	—
547B-20-2, 92–104	893.48	B	1.63	188	37	428	16	9	12	79
547B-21-2, 16–19	897.18	Matrix from debris flow	0.51	68	89	428	—	—	—	—
547B-22-1, 13–18	905.16	A	1.03	31	46	421	13	21	21	58
547B-22-1, 38–42	905.40	Claystone	0.44	18	167	419	—	—	—	—
547B-23-1, 45–55	915.00	Nodular micrite and claystone	0.11	19	395	514	—	—	—	—

Note: — = not determined.
[a] M. Bradshaw, personal communication 1982: facies type A to C are different "black shales" based on sedimentological criteria only. Details to be published.

Table 1: Rock Eval pyrolysis and liquid chromatography data published by Rullkötter et al. (1984)

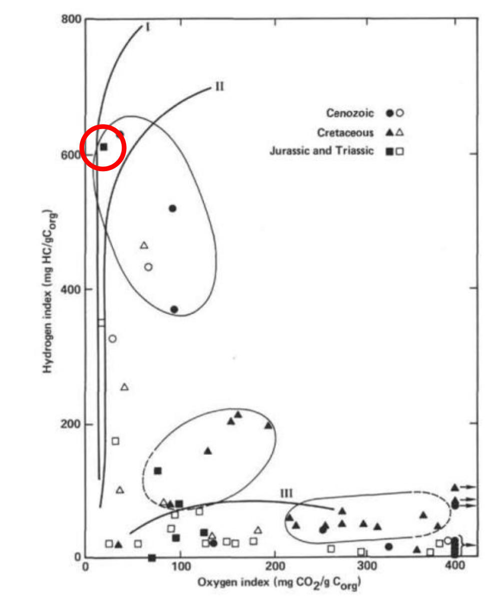


Figure 3: HIxOI diagram (modified from Rullkötter et al. (1984).

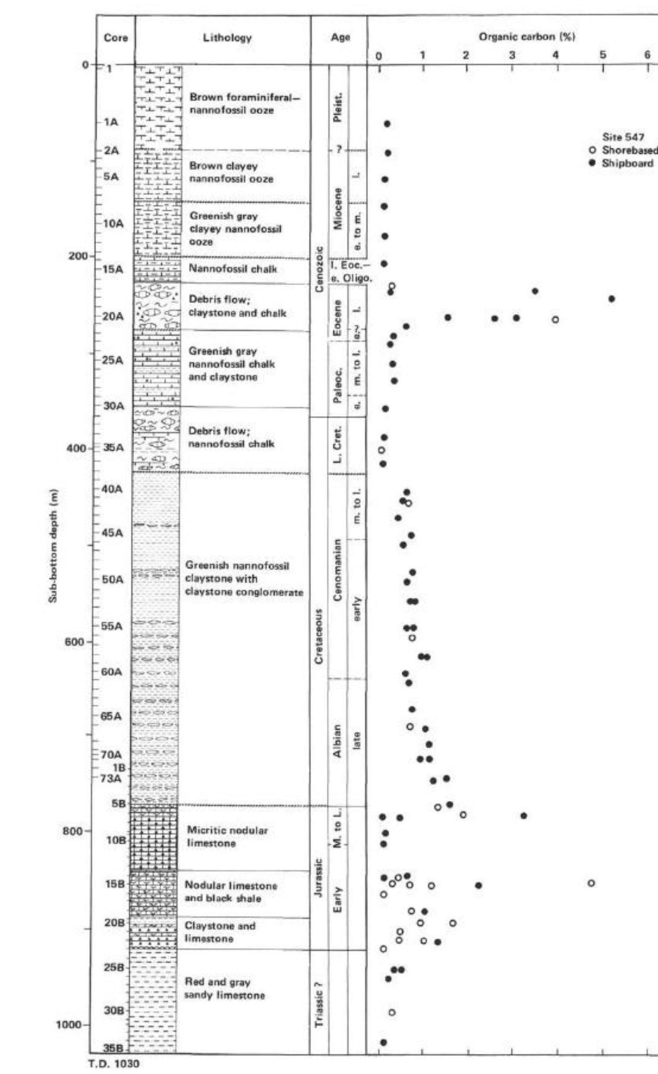
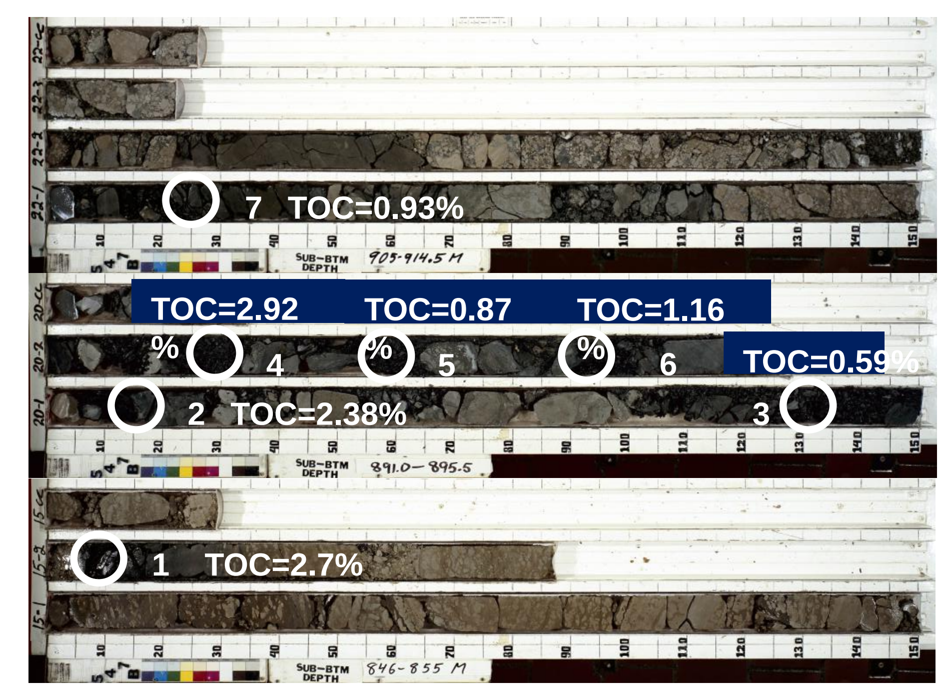


Figure 4: TOCxDepth plot from DSDP 547B well (modified from Rullkötter et al. (1984).

Mazagan Sub-basin, Offdhore Morocco

At DSDP site 79, in the 547B well, there is only 1 black square (early data measured shipboard) with HI>600 (mg/g TOC). The next square is white (measured on shore) with HI=345 at 847.60m. This value is just 5 cm away from our sample at 847.55m that shows a HI=150.
Table 1 (this Plate) published by Rullkötter et al. (1984) of data acquired onshore, did not report the HI>600 (red-circled; In the HIxOI plot published by Rullkötter et al. 1984).

Rock Eval pyrolysis data carried out for the PFA 2011 study di not reproduce either the high HI value of 600 (mg/g TOC) measured shipboard. The PFA 2011 Rock Eval pyrolysis results are listed in Table 2 of this Plate. 2 data points worth considering (HI>100) from Table 1 published by Rullkötter et al. (1984) are added to the data Table from PFA 2011



Picture of the cores analyzed by Rock Eval pyrolysis for PFA 2011 study

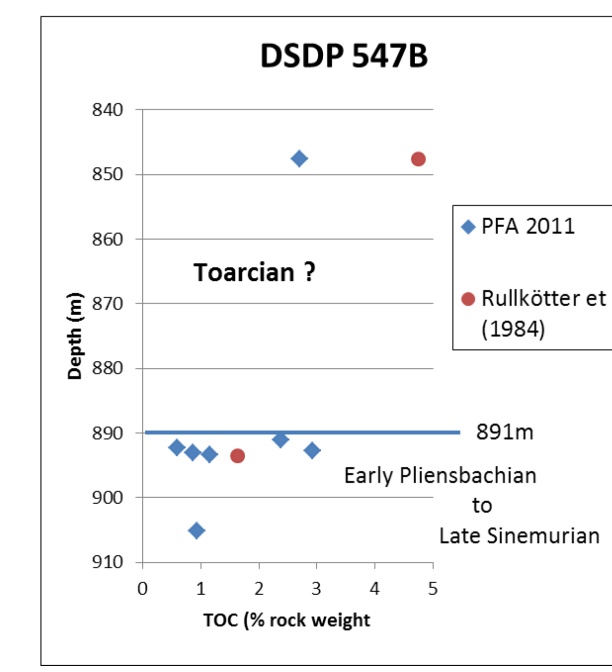


Figure 5: TOCxDepth plot from DSDP 547B well (PFA 2011 & Rullkötter et al. (1984)).

Table 2: PFA 2011 Rock Eval pyrolysis data. 2 data points worth considering (HI>100) from Table 1 published by Rullkötter et al. (1984) are added to the data Table form PFA 2011

Depth	Sample	Qty	Tmax	S1	S2	S3	PI	S2/S3	PC(%)	TOC(%)	HI	OI
0	9107	70.7	442	0.74	12.21	0.55	0.06	22.20	1.11	5.05	242	11
847.55	4421954	70.0	423	0.10	4.04	2.87	0.02	1.41	0.47	2.70	150	106
[a]847.60	na	na	421	na	16.38	0.71	na	23.07	na	4.75	345	15
891.11	4421955	70.9	423	0.13	8.82	1.94	0.01	4.55	0.82	2.38	371	82
892.30	4421956	70.3	423	0.03	0.25	1.56	0.10	0.16	0.08	0.59	42	264
892.79	4421957	70.6	425	0.10	6.31	1.71	0.02	3.69	0.61	2.92	216	59
893.01	4421958	70.1	425	0.04	0.63	1.80	0.05	0.35	0.12	0.87	72	207
893.39	4421959	70.3	491	0.00	0.01	1.78	0.21	0.01	0.07	1.16	1	153
[a]893.48	na	na	428	na	3.06	0.60	na	5.08	na	1.63	188	37
905.20	4421960	70.6	425	0.05	0.53	1.61	0.08	0.33	0.11	0.93	57	173
0	9107	70.4	442	0.72	12.18	0.63	0.06	19.33	1.11	5.09	239	12

[a] Rock Eval pyrolysis data worth considering from Rullkötter et al. (1984)

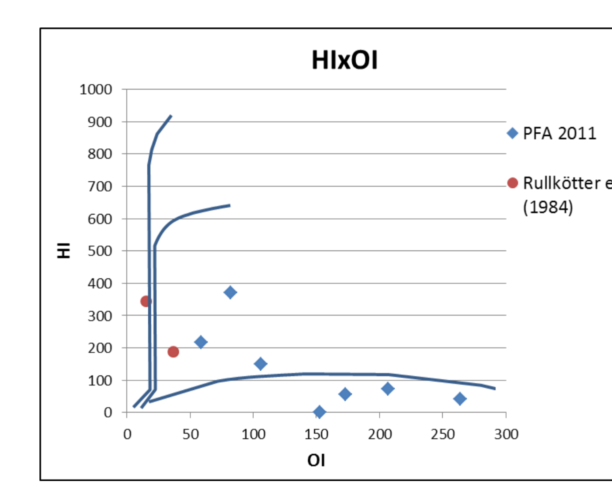
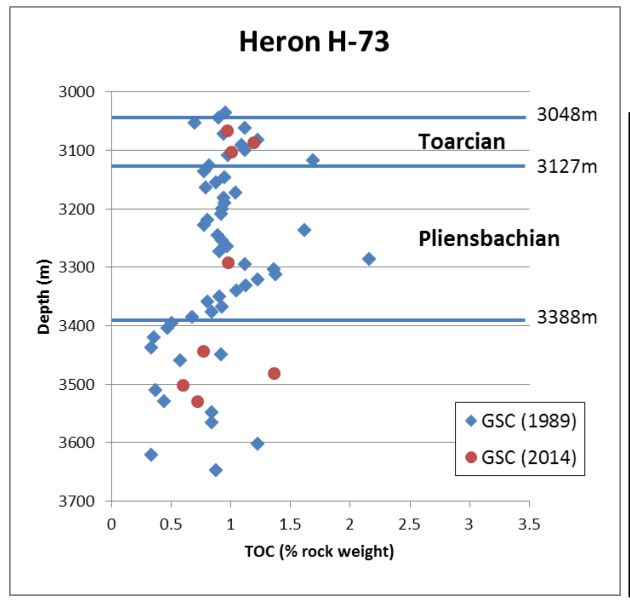
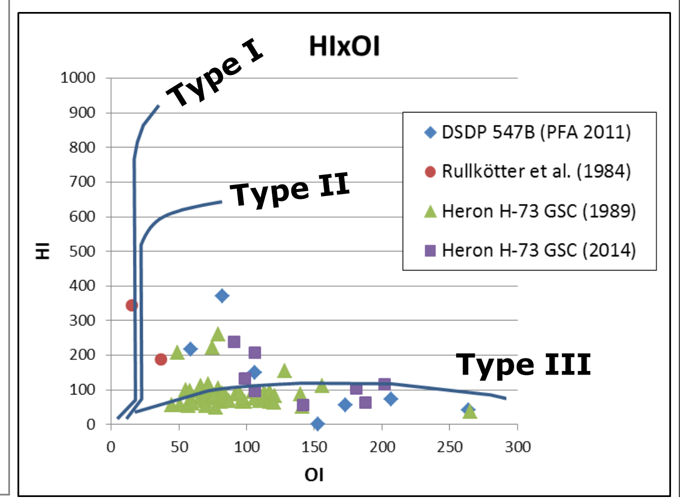
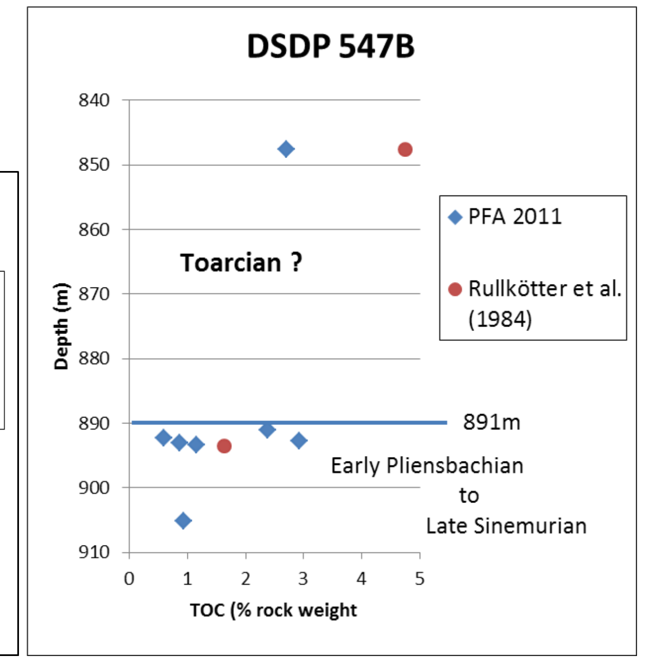


Figure 6: HIxOI diagramm from DSDP 547B well (PFA 2011 & Rullkötter et al. (1984)).







Comparison of the source characteristics in the Sinemurian/Pliensbachian/Toarcian sediments between Heron H-73 & DSDP 547B well.

<u>Differences</u> are depth of burial and therefore maturity of the Sinemurian/Pliensbachian/Toarcian:

- *Mature in Heron H-73,*
- *Immature in DSDP 547B.*

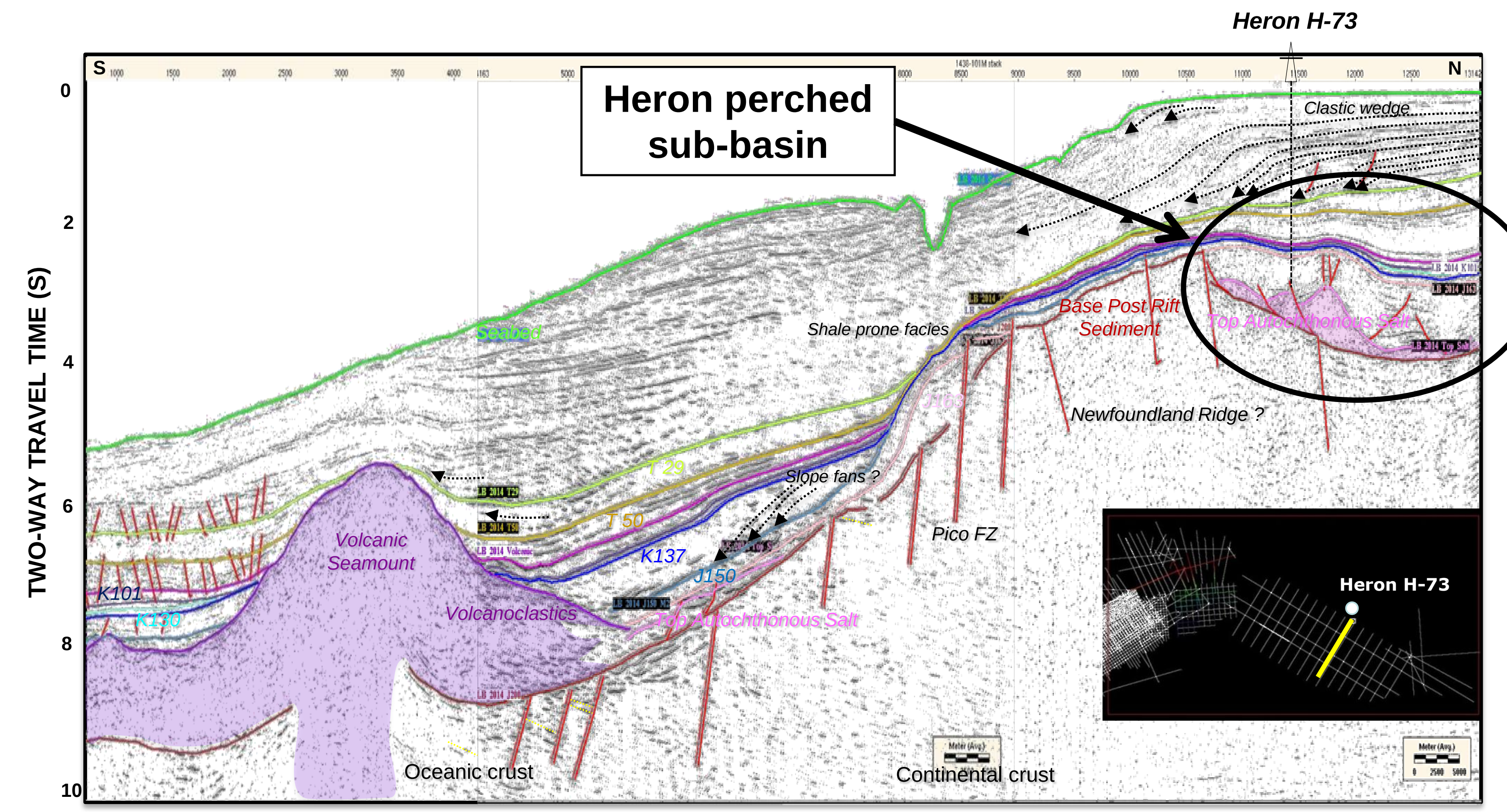
<u>Similarities</u> in both wells:

- *TOC values display a similar order of magnitude in both wells.*
- *HIxOI shows also similar source potential in both wells suggesting terrestrial input and/or partly oxidized organic matter.*

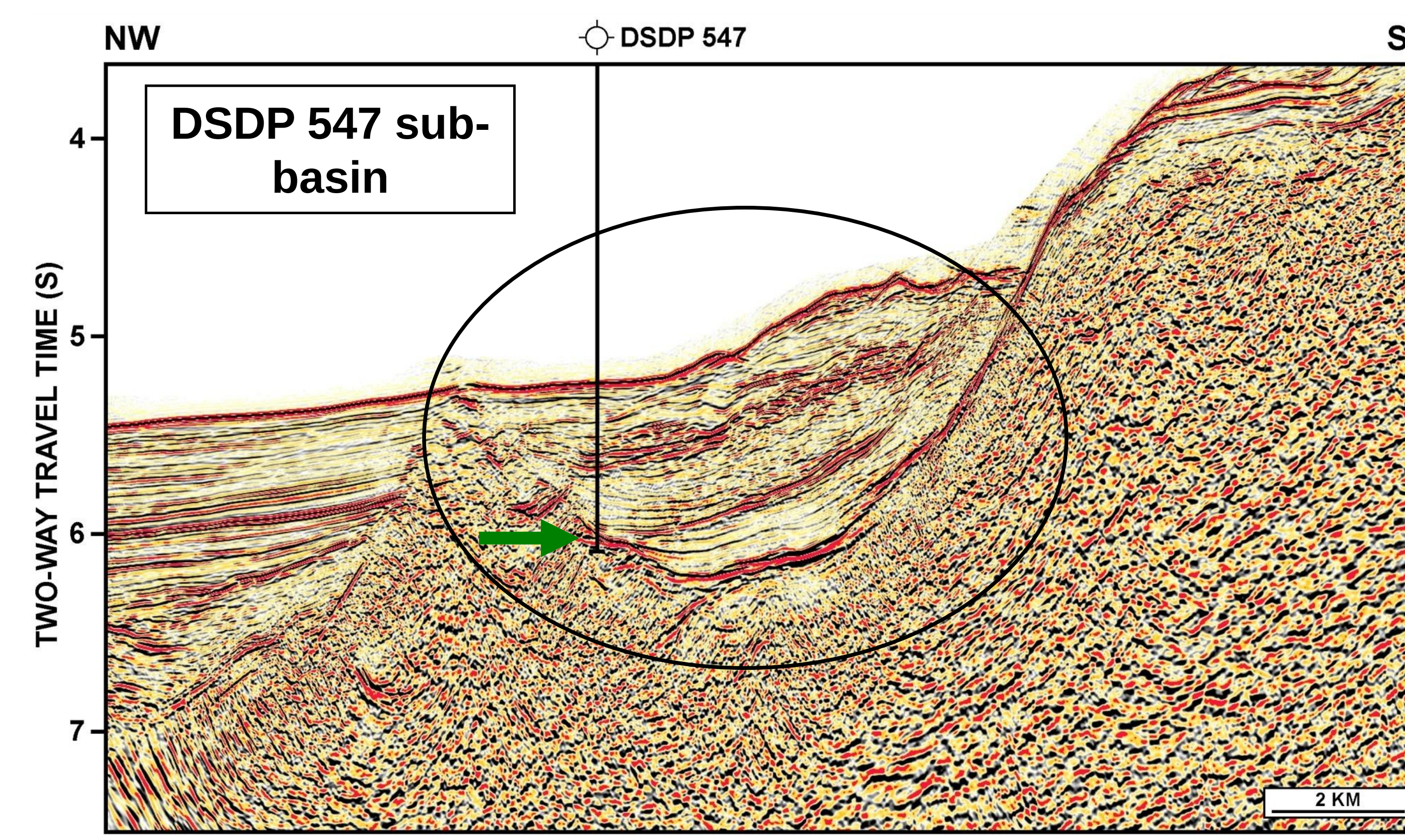
These characteristics bode well with terrestrial input and/or oxic to sub-oxic environment of deposition in "perched sub-basins" as shown by the seismic sections (right side of this Plate)

Arguments for Early Jurassic sourcing

- An Early Jurassic sourcing for DST#6 oil (~2300m) at Heron remains uncertain (see PFA 2011).
- Presence of Sinemurian-Pliensbachian-Toarcian age nannofossils in the basal sediments of both Heron H-73 and the DSDP 547B well off the Moroccan coast links the development of these perched basins on both margins of the Atlantic rift;
- Rock Eval source parameters in the Sinemurian-Pliensbachian-Toarcian part of the Heron section look very much like the ones that were measured in the DSDP 547B well at the same age with around 2% TOC and HI moderate (Type II-III) lower in Heron compared to 547B possibly due to the maturity
- This similarity on both margins suggests that Heron and the 547B wells were located in small aborted graben (see Mazagan) located behind the main rift valley on both sides of the incipient Atlantic rift.
- This leaves the possibility that in the main central rift valley the equivalent Sinemurian-Pliensbachian source layer(s) might be much better developed , i.e. thicker with higher TOC & HI, and deposited in a water stratified environment marked by the presence of Gammacerane (Peniche peninsula of Portugal and Cape Juby (M02) oil offshore Morocco; in PFA 2011).



Line 1438-101-M stack



2D Dip-oriented Seismic Line RS-131

Source rock characteristics

Lower Cretaceous – Aptian (deltaic)

The source rock was deposited during the Intra-Aptian flooding event as a prodeltaic facies of the incipient Logan Canyon/Cree deltaic development. The source interval coincides reasonably well with the Naskapi shale of the lithostratigraphic nomenclature. TOC/Rock Eval data defining the characteristics of this source rock are shown in Plate 5.4.2 for various wells from the Scotian Shelf and Slope. Organic richness is only fair with TOC averaging 2%. The organic matter composing this source rock is of a terrestrially derived Type III as is suggested by microscopic kerogen analyses and Hydrogen Index – Oxygen index cross plots shown in Plate 5.4.2.

The hydrocarbon kitchen applying to the Aptian source rock is practically never mature enough on the shelf to generate hydrocarbons. The maturity data (Vitrinite Reflectance) for various well locations indicate mostly immaturity except for wells located at present day shelf edge, e.g. Chebucto K-90. As a consequence of the limited kitchen, the Naskapi source rock does not appear to be a large contributor to the petroleum system of the Nova Scotia margin.

For modeling purpose, the Naskapi source rock is defined as follows:

- TOC=2%
- Kerogen Type III, using default Type III from Temis.

Lower Cretaceous – Berriasian (deltaic)

The age of this source interval is Berriasian-Valanginian (from K137 up) depositing as prodeltaic and paralic facies of the “middle” Missisauga delta. The Lower Cretaceous source rock is absent on the Jurassic carbonate shelf edge. That source interval is diffuse. Organic richness is mostly limited to TOC<1.5% and the kerogen is of a Type III. Plate 5.4.3 displays the characteristics of the Berriasian-Valanginian source rock.

The main reason for defining this interval as a source rock is to test its effect on the petroleum system modeled with Temis.

For Temis petroleum system modeling, the following characteristics are applied:

- TOC=2%
- Kerogen Type III, using default Type III from Temis.

Upper Jurassic – Tithonian MFS (carbonate transition to deltaic)

The Upper Jurassic source rock is present beyond the Jurassic carbonate bank edge. It was deposited at the transition from carbonate to deltaic environments of deposition during the Tithonian maximum flooding event. The source rock of the Tithonian MFS defined here corresponds to the lower part of the Verrill Canyon formation cited as source interval in P. K. Mukhopadhyay reports and publications. This Upper Jurassic source rock was difficult to identify due to drilling with oil-based mud (Lignosulphonate, Gilsonite and others) at the approach of overpressures, which is almost always coincidentally with approaching the Jurassic. Oil-based mud contamination strongly affects TOC/Rock Eval data usually by improving the response of these measurements to anomalously high values. The best and only way to overcome the distortion on Rock Eval analyses in defining source rock characteristics is to rely on kerogen microscopy, which allows for discriminating at least solid contaminants. In that regard, Mukhopadhyay’s work through the years is key for defining the Tithonian MFS as a prominent source rock of the deltaic region of the Nova Scotia margin.

Plate 5.4.4 displays the characteristics of the Tithonian source rock in various wells of the margin. South Griffin J-13 was not screened by kerogen microscopy,.

For Temis petroleum system modeling, the following characteristics are applied:

- TOC=5%
- Kerogen Type II-III.

Middle Jurassic – Misaine - Callovian MFS

Evidence for a Callovian source rock is limited to one well - Abenaki J-56 - located at the edge of the Jurassic platform. The extension of this source rock beyond the carbonate platform edge is unknown. In lithostratigraphic terms, this source rock corresponds to the Misaine Member. The Misaine is a shale dominated layer deposited during the Callovian flooding event. After Mukhopadhyay (1989), the Misaine in the Cohasset D-42 well is of Type III to IIB. In the new stratigraphic framework of this study, the source rock interval coinciding to the Callovian MFS is restricted to the part showing a kerogen Type IIB that is condensate/gas prone in Mukhopadhyay classification. Plate 5.4.5 displays the characteristics of the Callovian source rock in the Abenaki J-56 well, where it was penetrated and showed significant source potential.

For Temis petroleum system modeling, the following characteristics were applied:

- TOC=3%
- Kerogen Type IIB (II-III; standard)

Early Jurassic Source Complex - Sinemurian-Pliensbachian-Toarcian

A Sinemurian-Pliensbachian-Toarcian source complex was inferred by analogy to source rocks recognized on the conjugate margins of Newfoundland and Nova Scotia, in Portugal and Morocco. The Sinemurian immediately overlaying the Argo salt would offer a confined hypersaline environment, where source rocks are known to have deposited in rift basins. These confined environments are often prone to the development of ciliate bacteria, which are precursors of the Gammacerane molecule. Gammacerane was seen in the Pliensbachian source rock of Portugal (Peniche Basin) and in Moroccan oils. On the Scotian Shelf, one condensate from DST#6 of the Venture B-13 well and hydrocarbon fluids from salt inclusions in the Weymouth A-45 well display the presence of Gammacerane. Usually, DST hydrocarbon fluids are clean from mud contamination. However, if mud with Gilsonite additive was used and the formation tested was partly invaded by mud before testing, there is a chance that the DST fluids be contaminated. On the other hand, in the case of fluid inclusions in salt from the Weymouth well, the presence of Gammacerane is to be trusted as sample cleaning is drastic before crushing the inclusions for gas-chromatography (GC) and GC/mass-spectrometry (GCMS) analyses. The Toarcian penetrated in the 547B well of DSDP Leg 79, Site 547 did not display any Gammacerane leading to the conclusion that Gammacerane is not necessarily a criterion for defining the contribution of a Toarcian source rock. Depending on the environment whether hypersaline or not, Gammacerane may or may not be present. Along the Nova Scotia margin, Gammacerane may be associated to a source rock depositing at the end or immediately after the salt of the Argo Formation. At Pliensbachian and Toarcian time, the environment has possibly evolved into a carbonate environment no longer hypersaline or presenting any other water stratification of any type. This would be the case of the 547B well off Morocco, which penetrated the Liassic section down to a crystalline basement without penetrating any salt and not displaying any Gammacerane. In the Nova Scotia margin, the extension of a hypersaline source rock would be limited to the main rift area occupied by the autochthonous salt of the Argo Formation. Later, once spreading had started, restricted conditions and hypersalinity ceased as the basin opened. Sediments could deposit further, beyond the autochthonous salt area, over the ECMA volcanics. Source rocks depositing then would no longer contain Gammacerane by lack of water stratification (halocline in this instance). In time succession, the hypersaline source rock would preferably be Sinemurian deposited approximately just before spreading. Then, source rocks depositing later during early spreading may lose hypersaline characteristics, these would be Pliensbachian – Toarcian in age. To summarize, one or more Early Jurassic source rocks may exist. Their presence is unproven but is worth considering based on the conjugate Moroccan margin.

For Temis petroleum system modeling, one source rock only is defined for the Sinemurian to Toarcian source complex with the following characteristics:

- TOC=5%
- Kerogen Type II

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